THE DRYING CHARACTERISTICS OF CHEMICALLY DE-GUMMED FLAX FIBERS AND WATER-RETTED FLAX STRAW

A THESIS

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FLAX FIBERS AND WATER-RETTED FLAX STRAW

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF FIGURES
(Continued)

TABLE OF FIGURES
(Continued)

TABLE OF FIGURES
(Continued)

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I INTRODUCTION

Linen is often called the textile of luxury as its expense in the finer grades stands in the way of its common use. Linen at the present is preeminant for surgical uses and household purposes. No other textile is so free from lint, gives up its moisture so rapidly, is so easily cleansed and so pure and hygienic for constant use. Fabrics woven from other fibers are adulterated and cheapened, yet are acceptable with many consumers as the appearance is all that is really required of them, but with linen, it is in general the properties that are sought, and as all adulterations decrease these, pure linen is demanded. Linen is accorded a respect which we do not give to other textiles, for its long history, its old-time reliability, its exclusive command of many household needs, its purity and wholesomeness have given it a high record.

The great war almost destroyed the linen industry. Hemp and cotton had to be used in union with flax or in place of it, the supply of flax and of linen fabrics being almost exhausted. Linen was in demand for airplane wings and cordage and it was not until the closing months of the war that cotton was successfully adapted to these uses.

The contending armies fought on the best fields of Belgium, injuring them seriously for flax production. The mills of France and Belgium were destroyed by bombs or had the machinery carried away. When the war was over the flax industries of these two countries seemed hopelessly prostrate.

By 1931 little difficulty was found in obtaining any class of linen desired. The United States was importing more than ever before, the increase being notably from Czechoslovakia, Belgium, the Netherlands, Italy and France. Flax for fine linens is neither grown nor manufactured in the United States, but flax is planted extensively for seed. Methods of cultivation of flax are largely what they were in the time of the Pharaohs. Suggestions have been made and machines have been built for more rapid means of harvesting the crop and preparing for spinning but this treatment has proved injurious to the fibers.

The world flax production has increased rapidly since the war, with the exception of Russia and Latvia. Today, the nations of Europe are again at war and the flax industries there will undoubtedly be paralyzed again as they were in 1914. So the United States stands out as the most encouraging field for the life and development of the flax industry. To this end the State Engineering Experiment Station at the Georgia School of Technology is engaged in designing new machines for the recovery of fibers from the flax straw and determining the best method of de-gumming the fibers chemically.

The whole research program may be thought of as the "cottonization" of flax.

Drying is an important step in the continuous processing of the fibers and it is essential that the true drying characteristics be known before suitable and efficient dryers can be designed. Flax has been dired in the past by exposure to direct sunlight, the moisture being removed by natural convection. This simple method of drying requires too much time for practical use, so it becomes essential that the flax straw and fibers be dried artificially.

II PURPOSE OF PROBLEM

The purpose of the problem is to determine the drying characteristics of water-retted whole flax straw and chemically de-gummed flax fibers so that a suitable and efficient dryer may be designed to speed up this step in the manufacture of linen from the flax straw.

III METHOD OF TEST

Determination of Equilibrium Moisture Contents of Flax Fibers. Three wire cartridges, made to fit inside a ten inch test tube, were filled with flax fibers and hung inside of a compartment dryer which was kept at a constant temperature and humidity. The samples were exposed to the air until they attained a constant weight, after which time they were fitted into the test tubes, tightly corked and immediately weighed on an analytical balance. These samples were then bone dried in an ordinary drying oven at 115°C. The above procedure was repeated for different conditions of drying air, the temperature and humidity being held at any desired value while the stock was reaching equilibrium with the surrounding air. The difference between the equilibrium and bone dry weights represents the amount of moisture held by the stock at the existing conditions and the three samples served to give three determinations of a single point on the equilibrium moisture content curves. The average of the three values were plotted as pounds of moisture per 100 pounds of dry stock as abscissas against percent relative humidity as ordinates at a constant temperature.

All samples contained an excess of moisture before being placed in the dryer, the values giving a true desorption curve. Absorption values were determined for several conditions by exposing dry samples to the surrounding air, but these values of equilibrium moisture content so determined fell within the limits of those for desorption at the same temperature and humidity. If there is a difference in these two curves it is so small that it could not be detected by this method of test.

Adaptation of Dryer for Drying Rate Measurements. The available compartment dryer was arranged so that it approached a tunnel dryer in operation. A plywood shelf was built directly under the air-inlet tubes which were located near the top of the dryer. The shelf restricted the path taken by the air and gave parallel flow over the stock. The wings, fitted on this shelf, were capable of being set at different angles, thus effecting different air velocities. With such an arrangement, part of the incoming air could be shunted around the drying stock, giving low air velocities; or all of the air could be restricted to a relatively small area, giving large air velocities. This set-up did not give a large enough range of air velocities for a proper study of its effect on drying rates so varying numbers of the air-inlet tubes were closed, giving air velocities varying from 100 to 1500 feet per minute.

Determination of Drying Rates.

A. General Procedure: Flax was loaded into a screen wire basket of large area and suspended from an arm of a balance by a wire. The balance was located on the top of the compartment dryer and the wire was allowed to hang through a hole in the top, the lower end of the wire being attached to the basket which hung in the drying air stream. Weighings were made at definite time intervals and these values were recorded. A control switch was placed on the dryer top so that the blower fans could be stopped momentarily for weighings. With this set-up the condition of the drying air remained constant throughout the entire run. After the rate of moisture removal had become quite small the operation was stopped and the sample bone dried. Runs were made for different air humidities, temperatures and velocities and for different values of thickness and water concentration of the samples.

B. Method of Loading Basket: In order to get a complete drying rate curve it is necessary to start with stock which has a water concentration above the critical value. This necessitated the loading of wet fibers so that they would be distributed over the basket area in uniform thickness. This was accomplished by lowering the basket into a tank of water which had flax fibers dispersed throughout its volume. As the basket was withdrawn an even layer of fibers collected over the basket area. The thickness of the fiber layer was controlled by the fiber "concentration" in the water. The basket was then allowed to drain before placing it in the dryer.

For aid in dryer design, runs were made on fibers which had been freed of their excess water by means of squeeze rolls as this is the condition of the fibers as they leave the present flax washing machine. Strips of pressed fibers were spread over the basket area in an even layer.

The stock thickness could be varied most easily by simply increasing the number of such layers. When high air velocities were employed a screen wire was put over the stock to prevent any loss during the drying process.

When flax straw was being dried it was only necessary to spread the water-retted straw evenly over the basket area, and place the screen over the top. Drying straw in large bales and in different size bundles was attempted but this proved very impractical as there was almost no removal of moisture from the interior of the bundles. Flax straw should be dried in a very loose condition, so that the air stream may come in contact with the individual straws. This fact is of much more importance here than in the case of the flax fibers as the straw contains a woody section which is extremely resistant to water removal.

C. Temperature and Humidity Control: These two variables were controlled automatically by compressed air regulators. The control devices were simply set at the proper points to give the desired air condition, the temperature and humidity remaining constant as long as settings were not changed. A Foxboro instrument was used to record the wet and dry bulb temperatures, the percent relative humidity being determined from these values.

IV THEORY

Mechanism of Drying Process. Water vaporizes from a very wet solid into air very much as it evaporates from a free water surface, the rate of evaporation being constant as long as the surface remains wet.[1] For porous solids water is fed to the surface by capillarity, being replaced by air which enters through a few larger openings.[2,3] This movement of moisture may be loosely termed "diffusion", although the movement is probably always due to capillarity. If the pores or capillary passages are small, the moisture reaches the surface as fast as it evaporates and vaporization will take place at the surface. If the material is of a loose structure, the surface is freed of moisture faster than the water arrives from the interior, thereby emptying the passages near the surface of their water. Vaporization then takes place beneath the surface of the solid and the vapor formed moves through the air filled passages in the relatively dry surface layer. A loose fibrous material allows the zone of vaporization to retreat from the surface, since the tendency of the water to come to the surface is small.

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[1] T.K.Sherwood, Am. Inst. Chem. Eng. Vol. 32,150,(1936)

[2] Sherwood and Comings, Ind. Eng. Chem. 26, 1096,(1934)

[3] Ceaglske and Kiesling, Am. Inst. Chem. Eng. 36, 211, (1940).

In surface evaporation the water has to diffuse from the surface of the material through the air film to the surrounding air stream, the thickness of the film depending on the velocity of the air, being thick with low air velocities and decreasing as the air velocities increase, but in no case disappearing. The inner layer of the air film in contact with the solid is maintained saturated as long as the concentration of the water on the surface is sufficient. It is known that the rate of vapor diffusion (weight per unit time) varies directly as the cross-sectional area of the path taken at right angles to the direction of vapor diffusion, directly as the difference of partial pressure of the vapor at the two points in question and inversely as the length of path. The air film thickness is indeterminate but it is a function of the air velocity. This removal of moisture is accompanied by a large consumption of heat, the heat supply coming from the drying air stream by conduction through the air film and being proportional to the temperature difference. As long as the surface remains wet it assumes the wet bulb temperature of the air, so that, for a given drying condition, the driving force remains constant, but as the water content of the stock decreases the moisture concentration on the surface finally becomes so small that the rate of evaporation decreases and, therefore, the surface temperature begins to increase. As the zone of evaporation retreats from the surface, the observed thermal resistance increases with the thickness of the surface layer through which heat must penetrate.[4]

Sherwood gives a drying rate curve (Figure 1) for a sulphite paper slab where the vapor removal is largely controlling throughout the falling rate period. In the portion b-c of the falling rate period, the rate is controlled by vapor removal from the unsaturated surface, and the principal factors affecting the drying are air velocity, temperature and humidity as in the constant rate period, the rate being independent of the thickness.

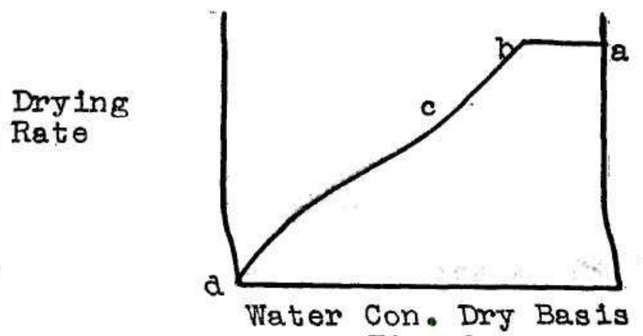

Fig. 1

In the portion c-d, as dryness is approached the rate of drying is determined by the rate of vapor transfer through the porous solid.

Believing that moisture movement in solids should be analogous to heat conduction in solids, a number of writers (Lederer,[5] Newman,[6] Sherwood,[7]) have developed

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[4] Sherwood, Ind. Eng. Chem. 22, 132, (1930).

[5] Lederer, Zeit. Angew. Chem. 37, 750, (1924).

[6] Newman, Am. Inst. Chem. Eng. 27, 203, (1931).
" " " " " 27, 310, (1931).

[7] Sherwood, Ind. Eng. Chem. 21, 12, (1929).
" " " " 24, 307, (1932).

theorectical equations relating the moisture content and time for various solid shapes. All of these developments were based on Fick's law, which states that the rate of moisture "diffusion" is proportional to the moisture gradient. In porous solids the movement would seem to be mostly by capillarity and Fick's law would not be applicable.

Equilibrium Moisture Content. It is well known that if a material is brough into contact with air of a definite temperature and humidity it will attain a definite moisture content that will be unchanged with further exposure to the air. This is known as the equilibrium moisture content of the material at the specified conditions. The percentage of absorbed moisture is dependent on the structure of the solid and always decreases with an increase in temperature and increases with an increase in humidity.

Free Moisture. Free moisture is defined as that moisture in a material which is capable of removal and is equal to the total moisture minus the equilibrium moisture. If a more complete removal of water is desired a higher air temperature or lower air humidity must be employed.

Critical Moisture Content. The critical moisture content of a material may be taken as the average water concentration at the end of the constant rate period. Its value depends on the rate of drying, decreasing as the rate increases.[8]

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[8] Sherwood and Comings, Ind.Eng.Chem., 26,1096,(1934).

This variation is not so great but the data obtained on flax fibers shows this property well.

Effect of Humidity on Drying Rate. If all other conditions are kept constant and the air humidity allowed to vary, the drying rate curves will be displaced up or down depending on whether the humidity is increased or decreased, the shape of the curve remaining unchanged. This effect is well established by data obtained by the author on drying rates of flax fibers.

Effect of Direction and Velocity of Air on Drying Rate. The rate of drying is greatly affected by air velocity so long as the surface is wet, the effect being analogous to the influence of fluid velocity on the dissipation of heat from a hot surface in contact with a fluid stream.

Sherwood presents data of many investigators on the effect of air velocity and direction on the rate of drying.[9] The data of Kamei and Sedohara on vaporization from wet sulphite pulp show a fairly constant vaporization rate with air velocities from 0 to 2 meters per second and a rapidly increasing rate for higher air velocities. Sherwood also suggests that since the effect of air velocity is analogous to its effect on heat transfer, it might be expected that the rate-velocity curves would not be linear, but should follow the

[9] Sherwood, Am. Inst. Chem. Eng., 32, 150, (1936).

power function relation with an exponent somewhat less than unity. See Equation (1) below.

$$W = 0.027\ V^{0.8}(p_s - p_a) \text{ ----- } (1)$$

W = rate of vaporization, Kg. per square meter per hour.
V = velocity of parallel air stream, meters per second.
p_s = V.P. of water at liquid surface temperature, Mm Hg.
p_a = P.P. of water in the air stream, Mm Hg.

Himus devised a power function with an additive term to take care of free convection but its more complicated form is not justified for estimates of drying rates. Sherwood recommends the more simple form as a conservative estimate of drying rates over a range of air velocities from 1.5 to 7.0 meters per second at room temperatures and shows that it is safer than a linear relation for extrapolation to higher air velocities.

Molstad, Farevaag and Farrell[10] showed that perpendicular air streams with velocities of 3-15 feet per second (mass velocities, G, of 800-4000 # per hour per sq.ft.) gave evaporation coefficients (K = # evap. per hour per sq.ft. per unit humidity diff.) which were about fifty percent greater than the accepted values for the evaporation of water into a parallel air stream. Increasing the air temperature did not alter the evaporation coefficient and drying rates on Celotex insulating boards gave evaporation coefficients for the constant rate period which were substantially the same as those

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[10] Molstad, Farevaag and Farrell, Ind.Eng.Chem., 32, 150, (1936).

for water under the same conditions.

Later work by Kamei, Mizuno and Shioni on drying rates of clays showed the effect of perpendicular air streams to be only slightly greater. It is well established that the direction of air streams does not have such a pronounced effect at high air velocities, but does greatly affect the drying rates at low velocities. Air velocity has its greatest effect on drying rate during the constant rate period, with its effect diminishing as the material approaches dryness.

<u>Effect of Porosity</u>. McCready and McCabe[11] show the effect of porosity on the drying rate and on the shape of the drying rate curves, giving the following curves to illustrate this effect:

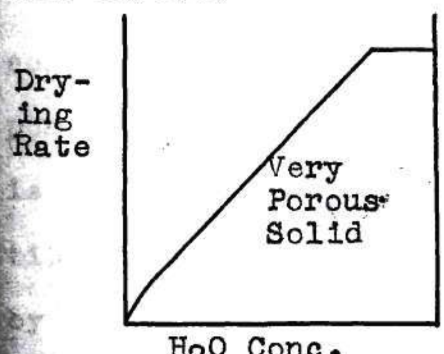

Fig. 2

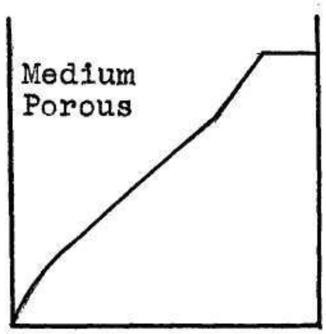

Fig. 3

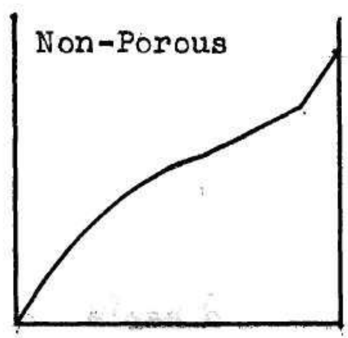

Fig. 4

As porosity decreases the thermal conductivity of the solid increases and the diffusion coefficient decreases, while the heat transfer coefficient through the air film and the coefficient of water vapor diffusion through the air film is unchanged.

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[11]McCready and McCabe, Am. Inst. Chem. Eng., 29, 131, (1933).

Effect of Heat Transfer by Radiation and Conduction.

If the heat of vaporization is supplied only by convection through the same surface air film through which vaporization takes place, the wet material assumes the true wet bulb temperature of the air stream. If heat is also received by radiation or by conduction, the dynamic equilibrium requires a higher solid temperature and the rate of drying is increased. Thus in practice the material is usually hotter than the wet bulb temperature during the constant rate period, and the drying rate is greater than would be calculated from Equation (1), Page 14, by assuming p_s equal to the vapor pressure of water at the wet bulb temperature.

The effect of radiation on the temperature of the wet solid may be calculated, providing the temperatures and the positions of the surrounding surfaces are known. The method is to equate the total heat input by radiation and convection to the heat required to vaporize water at the rate given by Equation 1, Page 14.[12] The resulting balance can be solved for the unknown temperature of the solid surface, t_s, and the vapor pressure, p_s, which are related by the vapor pressure curve.

The rate of drying from a wet surface, A, may be expressed approximately by the equation:

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[12] Sherwood, Ind. Eng. Chem. 21, 976, (1929).

$$\frac{dW}{d\Theta} = RA(H_s - H_a) \text{ ---------------- } (2)$$

where H_a is the absolute humidity of the air, H_s is the saturated humidity at the temperature of the surface of the solid and is a constant. Then by a heat balance,

$$\frac{dW}{d\Theta} = \frac{1}{r_s}\left[h_c A(t_a - t_s) + pCA(t_r^4 - t_s^4)\right] \text{-------} (3)$$

where p is the black body coefficient of the solid surface, C is the radiation constant in the Stefan-Boltzmann radiation equation, t_r is the absolute temperature of the surroundings, t_s is the absolute temperature of the solid surface, t_a is the absolute temperature of the air, h_c is the coefficient of heat transfer by conduction, A is the total area of the solid, and r_s is the latent heat of vaporization of water at the surface temperature.

It will be noted that this equation simply states that the rate of vaporization is equal to the rate of absorption of heat divided by the latent heat of vaporization, the first term within the brackets representing the heat flow by conduction through the surface air film and the second term, the heat absorbed by radiation from the surroundings. Combinining the above equations, the following relation is obtained:

$$r_s \frac{R}{h_c} (H_s - H_a) = t_a - t_s + \frac{pC}{h_c} (t_r^4 - t_s^4) \text{ ------- } (4)$$

Lewis has shown that for conditions of evaporation at the wet bulb temperature:[13]

$$\frac{h_c}{R} = S = C_a + C_w H, \text{-------------} (5)$$

the humid heat of the wet air, where C_a and C_w are the specific heats of air and water vapor respectively. Since h_c and R are primarily dependent on the gas film thickness and, within limits, not on the surface temperature, it might be expected that the relation above (Equation 5) would hold for evaporation at temperatures somewhat above the wet bulb temperature. Applying it, therefore, to the case in question:

$$\frac{r_s}{S}(H_s - H_a) = t_a - t_s + \frac{pC}{h_c}(t_r^4 - t_s^4) \text{ ---------} (6)$$

Since H_s is a known function of t_s, it is possible to solve the equation for t_s for any given set of conditions.

An example of the use of Equation 6 in the calculation of the effect of radiation on the relative drying rate for two sets of conditions has been calculated by Sherwood and plotted in Figure 5 as a function of the temperature of the surroundings. Values of the product $h_c(H_s - H_a)$ are plotted as ordinates which are seen from Equations 2 and 5 to be proportional to the rate of drying and the abscissas represent the temperature of the surroundings. The two curves shown are for different

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[13] Lewis, Ind. Eng. Chem. 13, 427, (1921).

values of the surface coefficient of heat transfer, h_c.

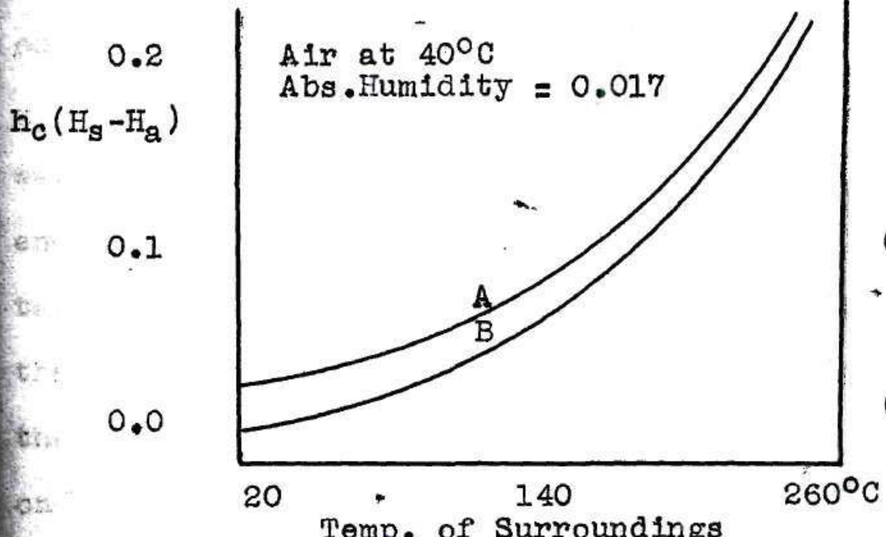

Fig. 5

$(A) h_c = \frac{0.00061\ Cal}{sec X Cm^2 x ^oC}$

$(B) h_c = 0.00034$ "

The effect of heat conduction is not easily calculated, but may be large. Materials dried on trays receive heat by conduction through the tray bottom, and the temperature of the wet material is increased although usually not to the dry bulb temperature. Since the vapor pressure of water rises rapidly with temperature, a small increase in the temperature of the solid may increase the rate of drying considerably.

<u>Moisture Movement by Capillarity</u>. When a tube of small internal diameter is placed upright with its lower end in a liquid, in general the level of the liquid inside the tube will not be the same as the level outside. This phenomenon is known as capillarity. If a liquid wets a tube (like water in glass), the liquid rises in it and if the liquid does not wet the tube (mercury in glass), it is depressed. The general free surface of a liquid is horizontal, but where the liquid is in contact with a solid, the surface is usually curved, the

direction and amount of curvature being different for different liquids and solids.

Consider the simple case of a glass capillary tube in water. The amount of pull per unit length of the circumference of the circle of contact is T, and the component of this, taken parallel to the length of the tube, is T cos a. For the whole circumference of the circle of contact the sum of these components is $2\pi r$ T cos a. This is an upward force on the liquid in the tube and it draws the liquid upward, until the weight of the liquid elevated above the ordinary surface equals the supporting force. If the mean elevation is h cms., the volume of the supported liquid is πr^2h cubic centimeters and its weight πr^2hpg dynes. Equating the two forces:

$$\pi r^2hpg = 2\pi rT \cos a \text{ -----(7)}$$

$$H = \frac{2T \cos a}{gpr} \text{ -------(8)}$$

It will be noted from Equation 8 that the elevation varies directly as the surface tension and inversely with the tube radius and liquid density.

Capillary action is not confined to the rise of liquids in capillary tubes. It occurs wherever there are minute crevices, pores, or tiny passages of any shape whatever. Capillarity explains the rise of oil in a lamp wick, the absorption of ink by a blotting pad or the absorption of water by a towel.

Comings and Sherwood[14] used a tapered capillary tube to show the mechanism of capillary movement of liquid water through a solid undergoing drying. When this capillary was filled with water and allowed to evaporate into the air of the room, it was noted that the small meniscus remained stationary at the small end of the tube while the larger miniscus moved continually from the larger to the smaller end until all the water had been evaporated.

In the drying of granular or porous solids, the capillaries are neither straight nor circular but the water is pulled through the passages in a manner similar to the movement through the tapered capillary tube. Water evaporates from the small menisci exposed at the surface of the solid, the small curvature of these surface menisci exerting a sufficient capillary pull to draw water through any passages ending in air-water interfaces of larger curvature. The water drawn to the surface is replaced by air which enters the solid through the larger passages connected with the larger openings at the surface. Because of the complicated interconnected passages beneath the surface, it is possible for the necessary air to enter through a relatively few surface openings and thus for the moisture concentration near the surface to remain relatively high. The water will continue to rise to the surface through any system of interconnecting passages until all the

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[14] Comings and Sherwood, Ind. Eng. Chem., 26, 1096, (1934).

various menisci at the lower ends of the water column have the same radius of curvature as the small menisci at the surface where evaporation is taking place. When this stage is reached, a small amount of evaporation from the surface menisci may result in a retreat of these surface menisci into passages of smaller cross-section and the increased capillary tension is sufficient to draw additional water to the surface.

As the drying proceeds, a time will be reached when the menisci at the lower ends of the water column in any system of interconnecting passages are, in general, about the same size as the smallest cross section of the surface openings, and water will no longer be drawn to the surface through these passages. Evaporation will continue from the surface menisci and the water in these surface openings will be freed to the surrounding air, thus causing the retreat of the surface menisci into the solid. The rate of drying will be retarded because of the necessity of the vapor formed to diffuse an appreciable distance through the air-filled passages to the surface. Sherwood has obtained experimental data on the drying of various solids which show that drying does take place from water surfaces in the interior of the solid. This was shown by the decrease in overall coefficient of heat transfer from air to solid measured by thermocouples placed at the center of the solid. As the solid dries, the tension exerted by capillarity results in a corresponding compression of the solid structure and a consequent strong tendency for the material to shrink. Sherwood makes the analogy between the moisture movement in a drying solid and the rise of sap in trees, explaining both movements on the basis of capillarity. It has long been established that the rise of sap in trees cannot take place by capillarity and hence this analogy is meaningless.

The falling-rate period of a drying process is, in general, divisable into two secondary periods, from which the mechanisms of drying prevailing in each may be called the zone of unsaturated surface drying and the zone where internal liquid diffusion is controlling. The former follows immediately after the critical point; the decrease in the rate of drying in this zone is due to a decrease in the wetted surface of the material. The surface is no longer completely wet, but dry portions of the solid extend out into the air film, so that the rate of evaporation per unit of total surface is decreased.

almost verbatim from Sherwood in Ch E Handbook

During the zone of unsaturated surface drying the resistance to the diffusion of vapor through the surface air film is the controlling factor. During the second zone of the falling-rate period the rate of internal diffusion controls the rate of drying. Obviously, if the initial water content is less than the second critical water content, internal liquid diffusion will control throughout the drying process.

Notes on Dryer Design.

A. General: If a single external heater is used, the air leaving the dryer is usually returned to the fan, only a portion being rejected. Such a dryer is adiabatic and the humidity is highest where the temperature is lowest, there being a decrease in the rate of drying at the air outlet. This may not be serious if the recirculation of air is large in comparison with the length of travel over the wet material in the dryer.

Dryers having internal heating units may be maintained at a constant temperature throughout and need not be supplied with heated air. Finned tube heaters should be used.

Proper circulation in most types of dryers is best obtained by means of fans located within the housing, since uniform air distribution is almost impossible with air supplied from an external blower. The most logical procedure is to make air circulation and supply quite independent of each other by employing internal fans for proper circulation and a single exhaust fan to remove the waste air at the proper humidity.

Principal heat requirements are:

1. Vaporization of water.
2. Heat in waste air.
3. Heat lost from dryer housing.
4. Heat required to heat stock and conveyor.

The principal items under the control of the designer are the heat lost in the waste air and the heat lost by convection and radiation to the surroundings, the latter loss being diminished by proper insulation.

There is a general misconception that sensible heat loss increases with exhaust air temperature, while actually the water vapor carrying capacity of air increases so rapidly with temperature that the decrease in the amount of air required more than offsets the increase in temperature and the sensible heat loss at 80°C will ordinarily be less than at 40°C. The curve of sensible heat loss versus exhaust temperature (given in the "Drying" section of Perry's Chemical Engineering Handbook) for fixed percents of relative humidity of fresh and waste air, goes through a maximum in the vicinity of 35°C. The reduction in sensible heat loss is, of course, offset by the increased heat loss from the housing if the temperature is raised too high.

As a compromise between air requirements and drying rates at different exhaust humidities, Sherwood suggests that the waste air should be maintained at about 60% relative humidity, and controlled by setting the damper in the waste air flue.

Estimation of Drying Time. Sherwood suggests a simple approximate relation between moisture content and drying time in the following equation:

$$\theta = \theta_c \quad \theta_f = \frac{T_o - T_c}{K'(T_c - T_e)} + \frac{1}{K'} \log_e \frac{T_o - T_e}{T - T_e} \text{ ----- (9)}$$

Where $K' = \dfrac{R'}{T_c - T_e} \dfrac{A}{W}$

T = average moisture content at time θ f, gms. H_2O per gm. solid.
T_o = initial water content.
T_e = equil. moist. content.
T_c = critical moist. content.
R' = drying rate over constant rate period.
A = wetted surface, sq. meters.
W = wt. of dry solid, Kg.

It was found that the above equation would check well with the experimental data for flax provided the following changes are made:

$$K = 1.8 \frac{R}{T_c - T_e} \cdot \frac{A}{W}$$

R = drying rate in constant rate period, $\frac{\#}{hr.\ ft^2}$

A = total drying area, sq.ft.
T, T_o, T_c and T_e, $\frac{\# H_2O}{\#\ dry\ flax}$

The following results show the applicability of the revised equation to drying data on flax:

Run	Fig.	*Calculated Time θ_t	Observed Time
V-F-2	14	260 min.	240 min.
H-F-2	9	108 min.	112 min.
H-F-3	10	130 min.	140 min.

B. Tunnel Dryers. Stock in the form of fibers or straw could be easily propelled through the dryer on an endless screen wire belt or any similar type of traveling conveyor.

In any case where the drying rate increases directly with air velocity it is desirable to increase the air velocity without changing the ratio of the rates of air and stock supply.

This may be done by recirculating the air across the stock and over the internal air reheaters by means of fans within the dryer.[15]

The drying air may be made to pass parallel or countercurrent to the direction of passage of the stock, the countercurrent method being superior for an efficient use of the heat and moisture-carrying capacity of the air. If it is necessary for the stock to leave the dryer with a definite percentage of moisture, or when so called case-hardening of the stock is liable to occur, parallel flow serves to give a more satisfactory control of temperature and humidity. Wherever allowable, heating elements should be arranged throughout the dryer space in order to keep the air at such a temperature that a satisfactory rate of evaporation may be obtained without overheating the product or causing excessive heat loss in the discharged stock.

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[15] Walker, Lewis, McAdams and Gilliland "Principles of Chemical Engineering."

V CALCULATION OF EQUILIBRIUM MOISTURE CONTENTS OF CHEMICALLY DE-GUMMED FLAX FIBERS

Sample Calculation:

Sample #1, 136°F, 13% R.H.

Total weight at equilibrium	=	12.672 grams
Weight of cartridge	=	10.163 "
Weight of stock at equilibrium	=	2.511 "
Weight of bone dry flax	=	2.456 "
Weight of equilibrium moisture	=	0.055 "

Grams H_2O/100 grams dry flax = #H_2O/100# dry flax

$$= \frac{0.055 \times 100}{2.456} = 2.24$$

These values of equilbrium concentrations are plotted against percent relative humidity as an equilbrium moisture content curve (Fig. 6).

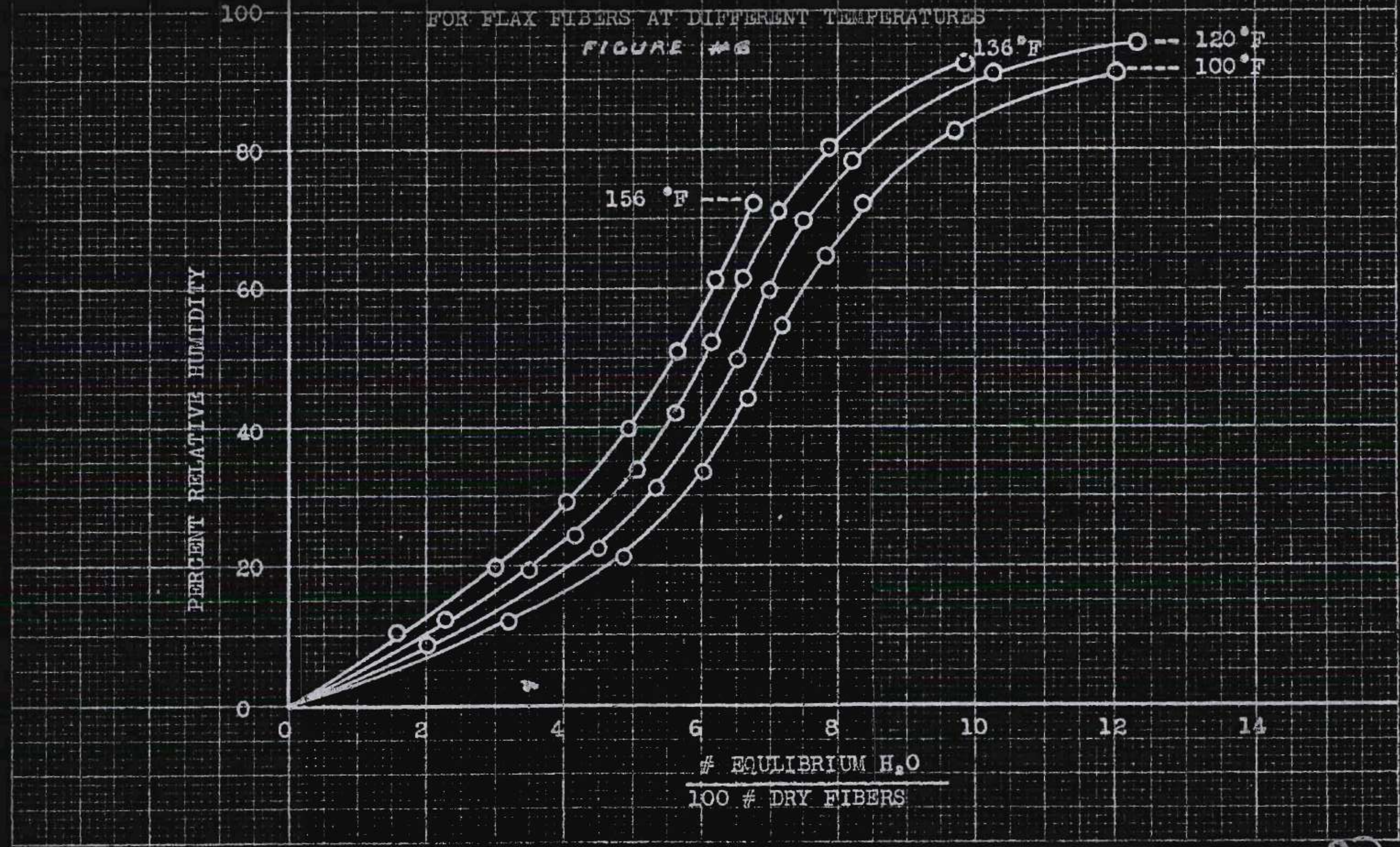
Discussion of Equilibrium Moisture Content Curves. The equilibrium moisture content curves for flax fibers show an increase in equilibrium moisture with increasing percentages of relative humidity at a constant temperature and an increasing percentage of equilibrium moisture for decreasing temperatures, the humidity being constant. This is in accordance with theoretical considerations and the general shape of the curves is similar to those for many other textile fibers.

Points on the curves represent the percentages of moisture in the stock which is incapable of removal by air at the temperature and humidity of that point. Values at temperatures and humidities other than those shown on the curves may be estimated with sufficient accuracy by interpolation and extrapolation.

PERCENT RELATIVE HUMIDITY VERSUS EQUILIBRIUM MOISTURE CONTENT

FOR FLAX FIBERS AT DIFFERENT TEMPERATURES

FIGURE #6



EQUILIBRIUM MOISTURE CONTENT RUN #[illegible] Wt. Cartridge = 10.[illegible] gms.
Dry Flax = 4.150 gms.

D.B. °F	W.B. °F	%R.H. %	Total Eq. Wt. gms.	Wt. Fibers at. Equ.	Total H_2O gms.	# H_2O / 100# Dry Flax
100	60	4	14.397	4.187	0.037	0.90
100	66	13	14.489	4.279	0.129	3.12
100	70	21	14.557	4.347	0.197	4.75
100	76	33	14.623	4.413	0.263	6.30
100	81	44	14.631	4.421	0.271	6.53
100	85	54	14.651	4.441	0.291	7.02
100	89	65	14.683	4.473	0.323	7.78
100	92	73	14.713	4.503	0.353	8.51
100	95	83	14.759	4.549	0.399	9.62
100	98	93	14.851	4.641	0.491	11.82

EQUILIBRIUM MOISTURE CONTENT RUN #2 Wt. Cartridge - 10.120
Dry Flax = 3.965 gms.

100	60	4	14.074	3.954	0.034	0.87
100	66	13	14.161	4.041	0.121	3.10
100	70	21	14.228	4.108	0.188	4.82
100	76	33	14.273	4.153	0.233	5.95
100	81	44	14.302	4.182	0.262	6.68
100	85	54	14.327	4.207	0.287	7.32
100	89	65	14.350	4.230	0.310	7.91
100	92	73	14.372	4.252	0.332	8.47
100	95	83	14.420	4.300	0.380	9.71
100	98	93	14.514	4.394	0.474	12.11

EQUILIBRIUM MOISTURE CONTENT RUN #3 Wt. Cartridge = 9.780 gms.
Dry Flax = 3.965 gms.

D.B. °F	W.B. °F	%R.H. %	Total Eq. Wt. Gms.	Wt. Fibers at Equ.	Total H_2O gms.	# H_2O 100# Dry Flax
100	60	4	13.754	4.004	0.039	0.93
100	66	13	13.837	4.087	0.122	3.08
100	70	21	13.907	4.157	0.192	4.83
100	76	33	13.943	4.193	0.228	5.75
100	81	44	13.983	4.233	0.268	6.74
100	85	54	13.992	4.242	0.277	6.96
100	89	65	14.022	4.272	0.307	7.72
100	92	73	14.044	4.294	0.329	8.28
100	95	83	14.103	4.353	0.388	9.77
100	98	93	14.195	4.445	0.480	12.07

EQUILIBRIUM MOISTURE CONTENT RUN #1 Wt. Cartridge = 10.163 gms.
Dry Flax = 2.456 gms.

120	75	10	12.668	2.505	0.049	2.00
120	84	22	12.729	2.566	0.110	4.50
120	90	31	12.756	2.593	0.137	5.60
120	96	41	12.770	2.607	0.151	6.15
120	101	51	12.778	2.615	0.159	6.51
120	104	60	12.785	2.622	0.166	6.78
120	109	69	12.803	2.640	0.184	7.52
120	113	79	12.823	2.660	0.204	8.32
120	117	91	12.870	2.707	0.251	10.24
120	118.5	95	12.919	2.756	0.300	12.25

EQUILIBRIUM MOISTURE CONTENT RUN #2 Wt. Cartridge = 10.210 gms.
Dry Flax = 3.959 gms.

D.B. °F	W.B. °F	%R.H. %	Total Eq. Wt. gms.	Wt. Fibers At. Equ.	Total H_2O gms.	# H_2O / 100# Dry Flax
120	75	10	14.250	4.040	0.081	2.05
120	84	22	14.347	4.137	0.178	4.50
120	90	31	14.392	4.182	0.223	5.63
120	96	41	14.411	4.201	0.242	6.11
120	101	51	14.425	4.215	0.256	6.46
120	104	60	14.438	4.228	0.269	6.80
120	109	69	14.459	4.249	0.290	7.52
120	113	79	14.500	3.290	0.331	8.35
120	117	91	14.580	4.370	0.411	10.40
120	118.5	95	14.649	4.439	0.480	12.12

EQUILIBRIUM MOISTURE CONTENT RUN #3 Wt. Cartridge = 9.750 gms.
Dry Flax = 4.111 gms.

120	75	10	13.947	4.197	0.086	2.10
120	84	22	14.056	4.306	0.195	4.75
120	90	31	14.087	4.337	0.226	5.51
120	96	41	14.107	4.357	0.246	6.00
120	101	51	14.127	4.377	0.266	6.48
120	104	60	14.138	4.388	0.277	6.75
120	109	69	14.160	4.410	0.299	7.30
120	113	79	14.197	4.447	0.336	8.24
120	117	91	14.281	4.531	0.420	10.22
120	118.5	95	14.381	4.631	0.520	12.65

[illegible]
Dry Flax = 2.456 gms.

D.B. °F	W.B. °F	%R.H. %	Total Eq. Wt. gms.	Wt. Fibers at Equ.	Total H_2O gms.	# H_2O / 100# Dry Flax
136	86	13	12.674	2.511	0.055	2.24
136	96	24	12.725	2.562	0.106	4.33
136	104	34	12.744	2.581	0.125	5.11
136	110	43	12.759	2.596	0.140	5.72
136	116	53	12.766	2.603	0.147	6.00
136	121	63	12.776	2.613	0.157	6.41
136	125	72	12.791	2.628	0.172	7.02
136	129	81	12.809	2.646	0.190	7.76
136	133	92	12.865	2.702	0.246	10.00

EQUILIBRIUM MOISTURE CONTENT RUN #2 Wt. Cartridge = 10.120 gms.
Dry Flax = 3.959 gms.

136	86	13	14.170	4.050	0.091	2.30
136	96	24	14.253	4.133	0.174	4.40
136	104	34	14.278	4.158	0.199	5.03
136	110	43	14.309	4.189	0.230	5.81
136	116	53	14.317	4.197	0.238	6.02
136	121	63	14.335	4.215	0.256	6.47
136	125	72	14.356	4.236	0.277	7.00
136	129	81	14.395	4.275	0.316	8.00
136	133	92	14.464	4.344	0.385	9.74

EQUILIBRIUM MOISTURE CONTENT RUN #3 Wt. Cartridge = 9.750 gms.
Dry Flax = 4.111

D.B. ^oF	W.B. ^oF	%R.H. %	Total Eq. Wt. Gms.	Wt. Fibers at. Equ.	Total H_2O gms.	# H_2O / 100# Dry Flax
136	86	13	13.952	4.202	0.091	2.27
136	96	24	14.038	4.288	0.177	4.31
136	104	34	14.072	4.322	0.211	5.14
136	110	43	14.095	4.347	0.236	5.75
136	116	53	14.109	4.361	0.250	6.08
136	121	63	14.126	4.378	0.267	6.50
136	125	72	14.151	4.401	0.290	7.06
136	129	81	14.185	4.435	0.324	7.89
136	133	92	14.268	4.518	0.407	9.92

EQUILIBRIUM MOISTURE CONTENT RUN #1 Wt. Cartridge = 10.163 gms.
Dry Flax = 2.456 gms.

156	96	11	12.656	2.493	0.037	1.51
156	106	20	12.683	2.520	0.064	2.50
156	116	30	12.715	2.552	0.096	3.92
156	124	40	12.728	2.565	0.109	4.45
156	132	51	12.763	2.600	0.144	5.87
156	138	61	12.772	2.609	0.153	6.25
156	143	71	12.786	2.623	0.167	6.80

EQUILIBRIUM MOISTURE CONTENT RUN #2 Wt. Cartridge = 10.120 gms.
AVERAGE OF THREE RUNS Dry Flax = 3.959 gms.

D.B. °F	W.B. °F	%R.H. %	Total Eq. Wt. gms.	Wt. Fibers at. Equ.	Total H_2O gms.	# H2O / 100# Dry Flax
156	96	11	14.140	4.020	0.061	1.54
156	106	20	14.177	4.057	0.098	2.50
156	116	30	14.238	4.118	0.159	4.02
156	124	40	14.253	4.133	0.174	4.40
156	132	51	14.305	4.185	0.226	5.71
156	138	61	14.311	4.201	0.242	6.11
156	143	71	14.335	4.225	0.266	6.72

EQUILIBRIUM MOISTURE CONTENT RUN #3 Wt. Cartridge = 10.210 gms.
Dry Flax = 4.000 gms.

D.B. °F	W.B. °F	%R.H. %	Total Eq. Wt. gms.	Wt. Fibers at. Equ.	Total H_2O gms.	# H2O / 100# Dry Flax
156	96	11	14.274	4.064	0.064	1.60
156	106	20	14.310	4.100	0.100	2.50
156	116	30	14.372	4.162	0.162	4.05
156	124	40	14.392	4.182	0.182	4.50
156	132	51	14.442	4.232	0.232	5.81
156	138	61	14.456	4.246	0.246	6.15
156	143	71	14.480	4.270	0.270	6.75

AVERAGE OF THREE RUNS FOR EQUILIBRIUM
MOISTURE CONTENT

D.B. °F	W.B. °F	%R.H. %	# H_2O (Equil.) / 100# Dry Flax
100	60	4	0.90
100	66	13	3.10
100	70	21	4.80
100	76	33	6.00
100	81	44	6.65
100	85	54	7.10
100	89	65	7.80
100	92	73	8.42
100	95	83	9.70
100	98	93	12.00
120	75	10	2.05
120	84	22	4.53
120	90	31	5.59
120	96	41	6.09
120	101	51	6.48
120	104	60	6.78
120	109	69	7.45
120	113	79	8.30
120	117	91	10.29
120	118.5	95	12.34

D.B. °F	W.B. °F	%R.H. %	# H_2O (Equil.) / 100 # Dry Flax
136	86	13	2.27
136	96	24	4.35
136	104	34	5.09
136	110	43	5.76
136	116	53	6.04
136	121	63	6.46
136	125	72	7.03
136	129	81	7.88
136	133	92	9.89
156	96	11	1.55
156	106	20	2.50
156	116	30	4.00
156	124	40	4.45
156	132	51	5.80
156	138	61	6.16
156	143	71	6.76

VI CALCULATION OF DRYING RATES AND EXPLANATION OF DRYING RATE DATA

To illustrate the general method of calculating drying rates, run V-F-2, Fig. 7, is taken as typical. (V-F-2 data on page 57).

1. Plot time in minutes against total weight in pounds as obtained experimentally.

2. Draw a smooth curve through these points, giving the time-weight curve.

3. Select some point, P, (W = 5.73, T = 167.50) on the time-weight curve and draw a tangent, CS, to the curve at this point.

4. Draw a line, BR, parallel to the X-axis and intersecting the Y-axis and the tangent, CS.

5. CB = 8.90 - 6.00 = 2.90 = W
   BR = 150.00 - 0.00 = 150.00 = T

6. Slope (dw/dt) of tangent, CS = 0.193
   2.90/150.00 = 0.0193#/min.

7. Drying area = 2 x area of one side of basket
   = 15 ft.^{2}

8. Drying rate at the point chosen on the time-weight curve = pounds of water removed per hour per sq. ft. of drying area = $0.0193 \frac{\#}{\text{min.}} \times \frac{60 \text{ min.}}{\text{hour}} \times \frac{1}{15 \text{ ft.}^2} = \frac{0.08\#}{\text{Hr.ft.}^2}$

9. Subtract from the value of the total weight at the point of tangency the weight of the assembly, thus obtaining the total weight of the stock.

Total stock weight = 5.73 - 4.25 = 1.48#

10. Subtract the weight of bone dry stock from the total weight of the stock to obtain the total moisture present. Total moisture present = 1.48 - 0.77 = 0.71#

11. Read the value of the equilibrium moisture content at these drying conditions from the equilibrium curves and subtract this value from the total moisture, obtaining the free moisture content. Free moisture = 0.71 - 0.03 = 0.68#.

12. Divide the pounds of free moisture by the pounds of dry stock, obtaining the water concentration at the point chosen on the time-weight curve. Water concentration = 0.68/0.77 = 0.89 $\frac{\#\text{free } H_2O}{\#\text{dry stock}}$

13. Determine drying rates and water concentration values for other points on the time-weight curve as shown above.

14. Plot the water concentration values as abscissas against the drying rates as ordinates, thus obtaining the drying rate curve.

15. It will be noted that the values ΔW and ΔT are not obtainable directly from the original time-weight data but are values derived as shown above.

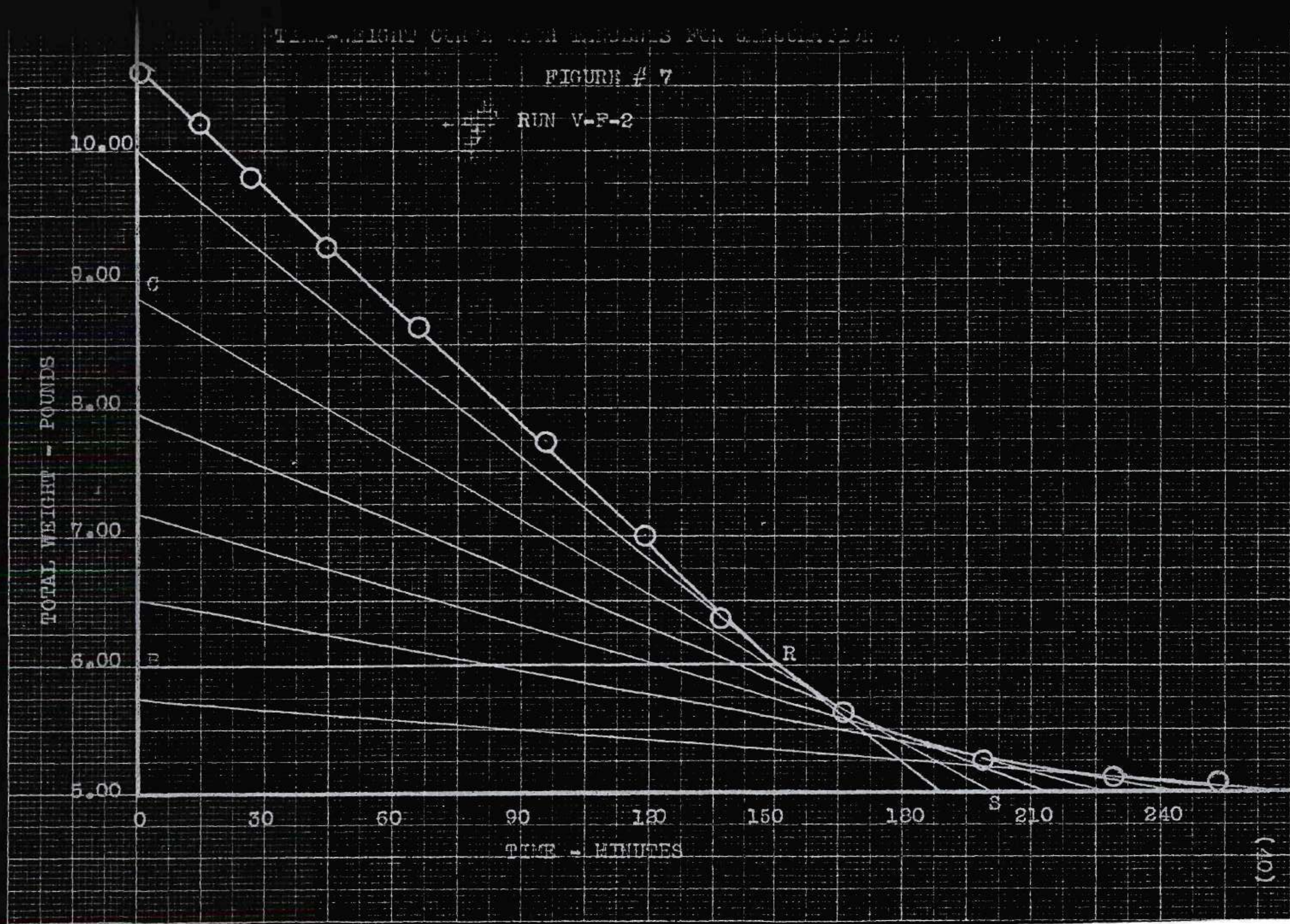


FIGURE # 7
RUN V-F-2
TOTAL WEIGHT - POUNDS
10.00
9.00
8.00
7.00
6.00
5.00
C
B
R
S
0
30
60
90
120
150
180
210
240
TIME - MINUTES

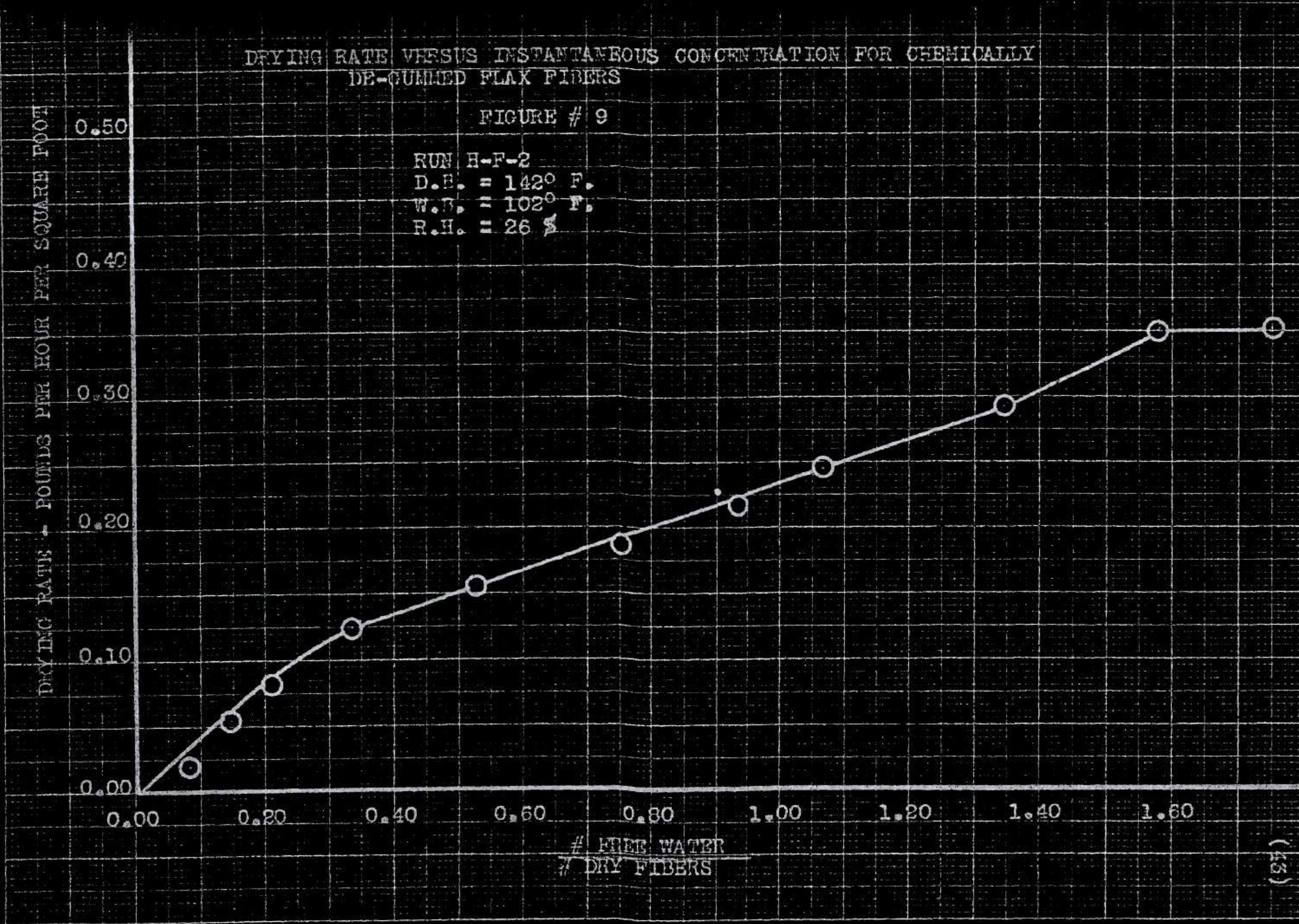
VII EFFECT OF OPERATING VARIABLES ON DRYING RATE OF CHEMICALLY DE-GUMMED FLAX FIBERS

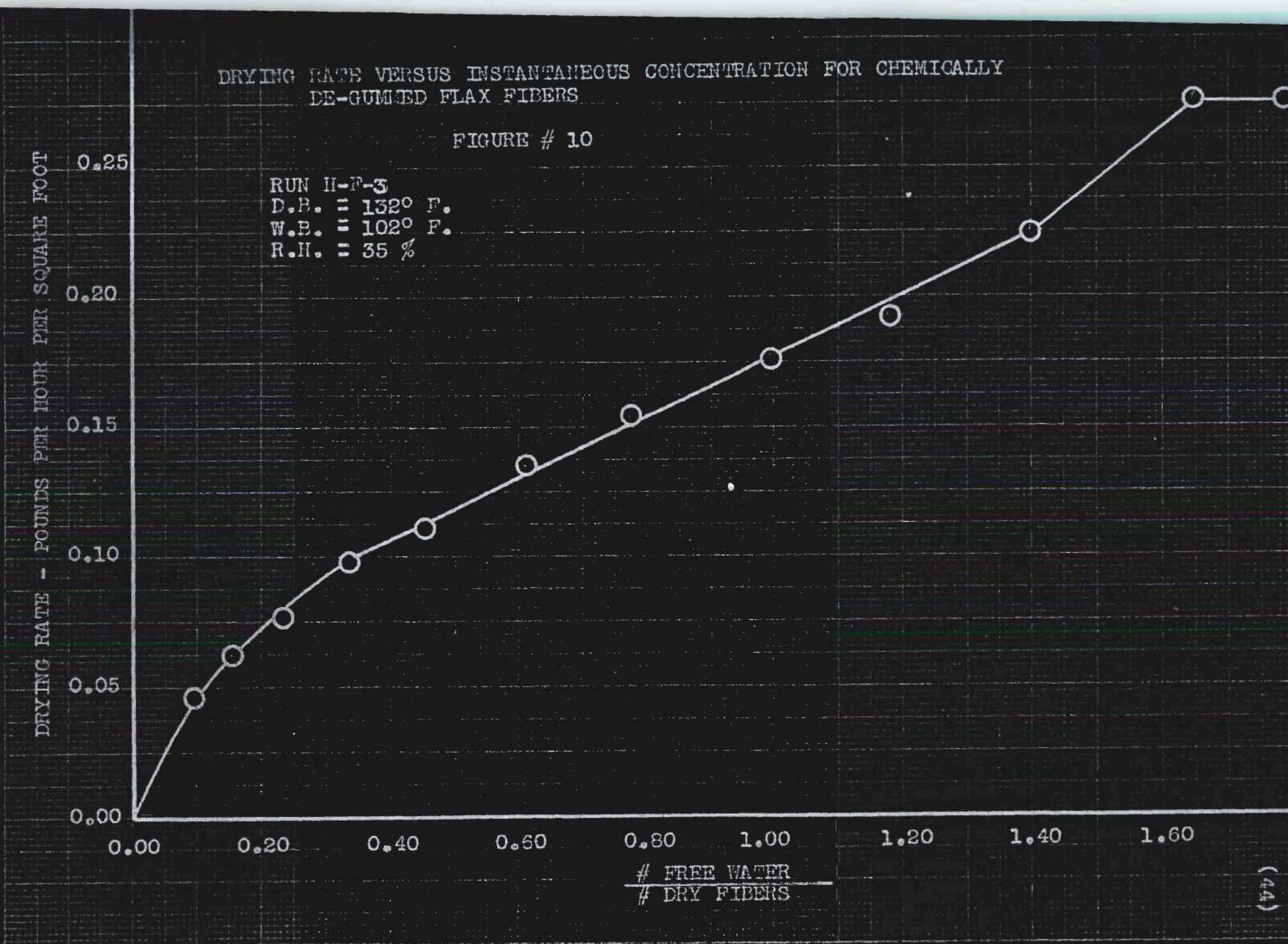
Effect of Humidity on the Drying Rate of Flax Fibers. In determining the effect of humidity on the drying rate of flax fibers, all variables were held constant except the percent relative humidity. In runs H-F-1, H-F-2, H-F-3, and H-F-4, Figures 8, 9, 10, 11, 12, the air velocity was maintained at 1500 feet per minute, thickness of fiber layer at 1/2 inch, wet-bulb temperature at 102°F. By varying only the dry-bulb temperature, the effect of humidity on the drying rate was readily studied.

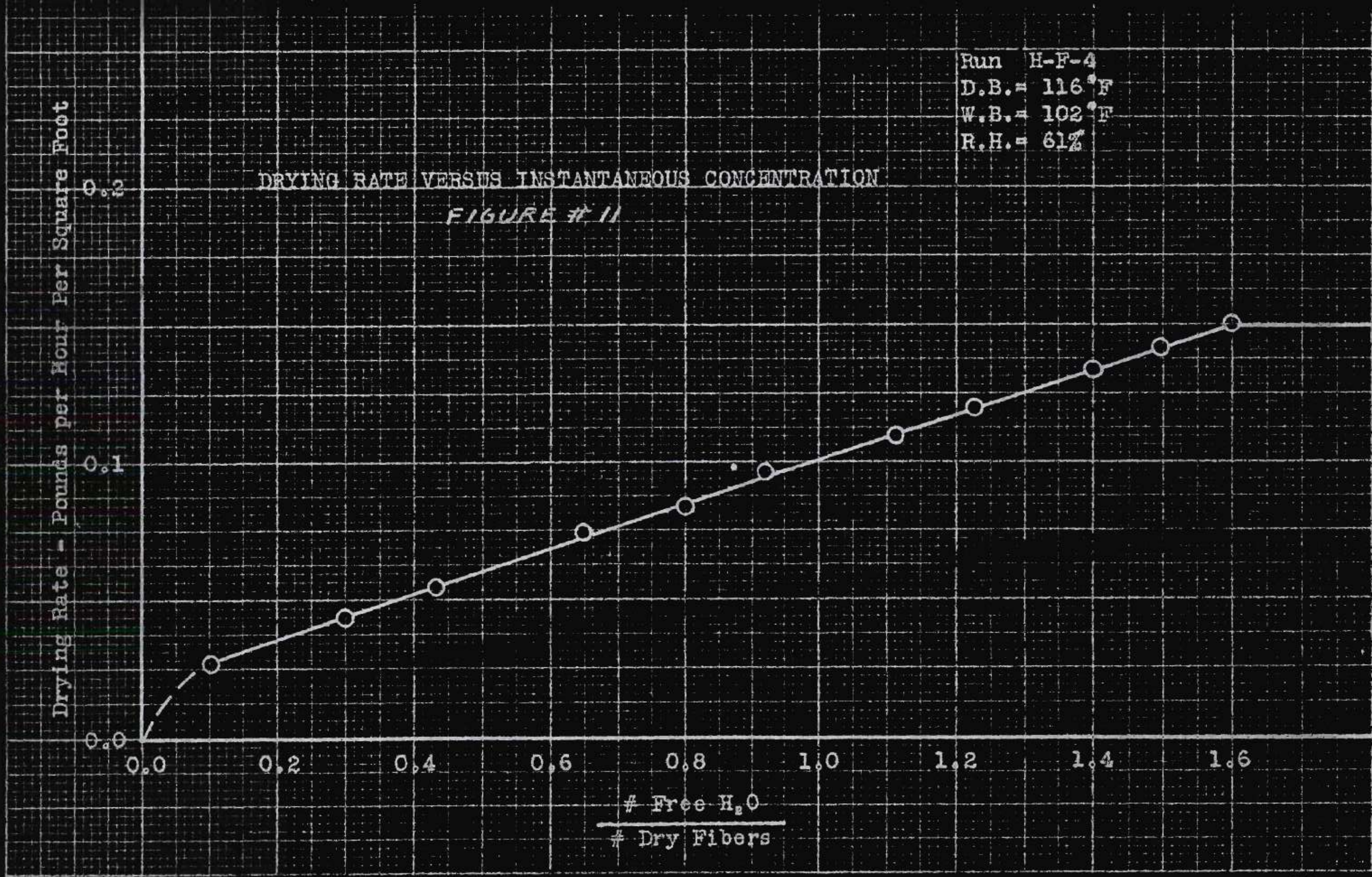
As the air humidity is varied from 5% to 61%, the rate curves are displaced vertically in proportion to the rate of drying through the constant-rate period. The effect of varying the air humidity is to vary the partial pressure gradient from air stream to vaporization zone and thus vary the drying rate in proportion to this difference. The rate of drying increases as the percent relative humidity is decreased, all other variables being held constant.

DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS

FIGURE # 8


DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS
FIGURE # 9
RUN H-F-2
D.B. = 142° F.
W.B. = 102° F.
R.H. = 26 %
DRYING RATE - POUNDS PER HOUR PER SQUARE FOOT
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
FREE WATER / # DRY FIBERS


DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY
DE-GUMMED FLAX FIBERS
FIGURE # 10
RUN H-F-3
D.B. = 132° F.
W.B. = 102° F.
R.H. = 35 %
DRYING RATE - POUNDS PER HOUR PER SQUARE FOOT
0.25
0.20
0.15
0.10
0.05
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
FREE WATER
DRY FIBERS

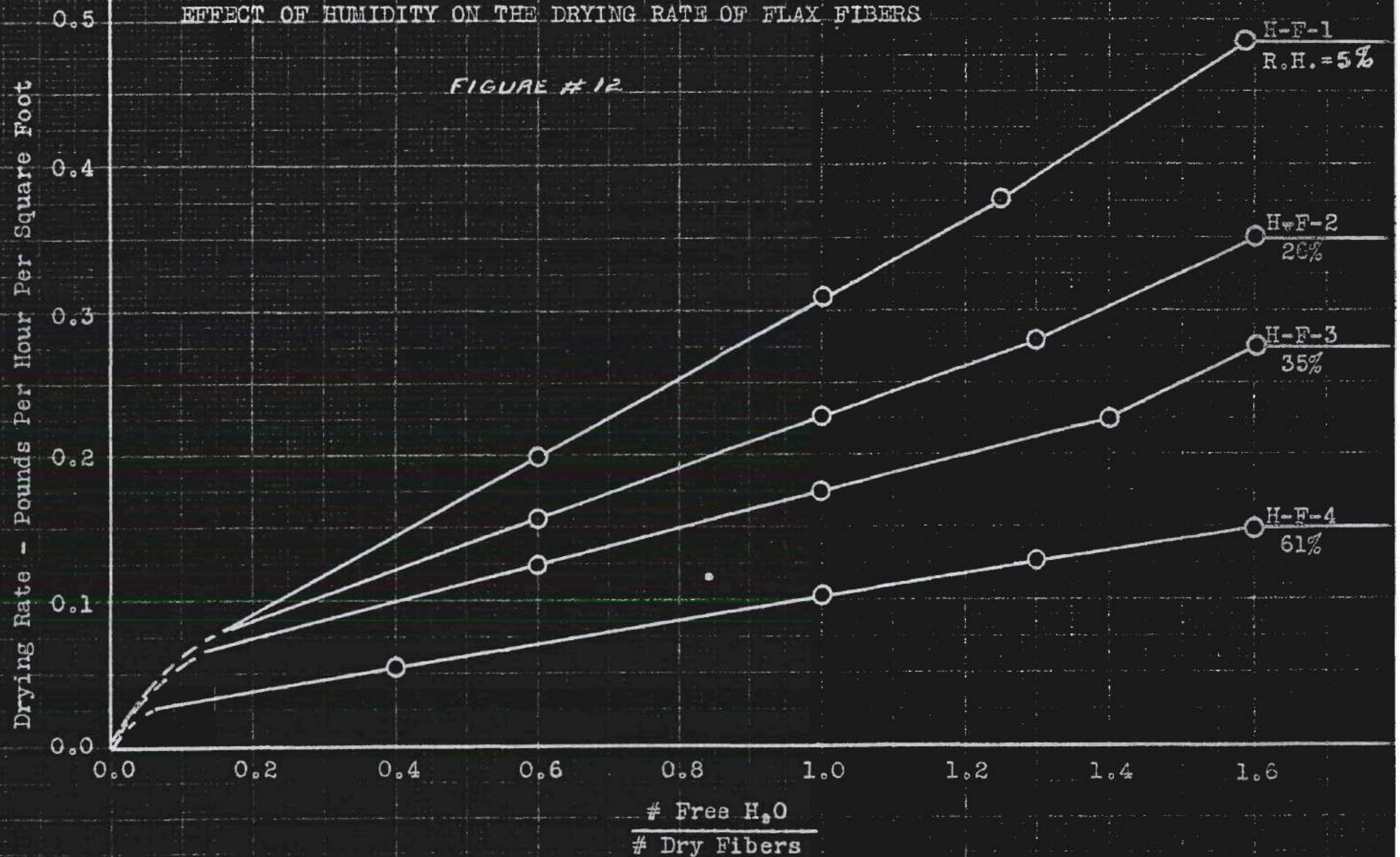


DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION

FIGURE # 11

EFFECT OF HUMIDITY ON THE DRYING RATE OF FLAX FIBERS

FIGURE # 12



RUN H-F-1 R.H. = 5% Wt. of Assembly = 4.56#
D.B. = 172°F Thickness = 1/2" Wt. of dry flax = 2.08#
W.B. = 102°F V = 1500 ft./min. Eq. H_2O = .02#

W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	#Free H_2O / #Dry Flax
12.45	2.55	21.10	0.49	5.81	5.79	2.78
9.90	2.55	21.10	0.49	3.26	3.24	1.55
9.40	5.30	54.50	0.39	2.76	2.74	1.31
8.95	4.90	58.00	0.34	2.31	2.29	1.10
8.55	4.45	61.00	0.29	1.91	1.89	0.90
8.20	3.95	65.00	0.24	1.56	1.54	0.73
7.93	3.48	68.00	0.20	1.29	1.27	0.61
7.70	3.10	72.00	0.17	1.06	1.04	0.50
7.50	2.65	74.50	0.14	0.86	0.84	0.40
7.35	2.20	77.50	0.10	0.71	0.69	0.33
7.20	2.00	79.00	0.10	0.56	0.54	0.26
7.10	1.25	56.50	0.09	0.46	0.44	0.21
7.00	0.50	27.50	0.07	0.36	0.34	0.16

Assembly = 4.56#
Dry Flax = 2.06#
Eq. H_2O = 0.07#

W.B. = 102°F RUN H-F-2 R.H. = 26% D.B. = 172°F Thickness = 1/2"

12.75	2.50	30.20	0.33	6.13	6.06	2.91
10.00	2.50	30.20	0.33	3.38	3.31	1.59
9.40	4.50	64.50	0.28	2.78	2.71	1.31
8.92	4.20	68,25	0.25	2.30	2.23	1.08
8.50	3.90	72.75	0.22	1.88	1.81	0.87
8.10	3.52	76.50	0.18	1.48	1.41	0.68
7.80	3.07	81.00	0.15	1.18	1.11	0.54
7.55	2.62	84.75	0.12	0.83	0.76	0.37
7.30	2.30	87.00	0.11	0.68	0.61	0.30

RUN H-F-2 (cont.)

W lbs.	W lbs.	T min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	# Free H_2O / #Dry Flax
7.14	1.83	89.25	0.08	0.52	0.45	0.22
7.00	0.71	54.20	0.05	0.38	0.31	0.15
6.94	0.70	90.00	0.03	0.33	0.26	0.13
6.89	0.37	85.50	0.02	0.27	0.20	0.10
6.85	0.07	60.00	0.01	0.23	0.16	0.08

Thickness = 1/2"

RUN =H-F-3
D.B. = 132° F

W.B. = 102°F
R.H. = 35%

Wt. Assembly = 4.56#
Wt. Dry Flax = 2.16#
Eq. H_2O = 0.07#

13.08	2.75	40.00	0.28	6.36	6.29	2.91
10.33	2.75	40.00	0.28	3.61	3.54	1.65
9.80	5.38	105.00	0.23	3.08	3.01	1.40
9.31	5.20	109.00	0.19	2.59	2.52	1.18
8.85	4.95	112.00	0.18	2.13	2.06	0.97
8.45	4.60	117.00	0.16	1.73	1.66	0.77
8.10	4.07	123.00	0.13	1.38	1.31	0.61
7.77	3.74	127.00	0.12	1.05	0.98	0.46
7.50	3.20	131.00	0.10	0.78	0.71	0.33
7.30	1.60	84.00	0.08	0.58	0.51	0.24
7.12	1.15	74.00	0.06	0.40	0.33	0.16
7.00	1.20	100.00	0.05	0.28	0.21	0.10

Thickness = 1/2"

RUN H-F-4
D.B. = 116°F

W.B. = 102°F
R.H. = 61%

Wt. Assembly = 4.56#
Dry Flax = 2.00#
Eq. H_2O = 0.12#

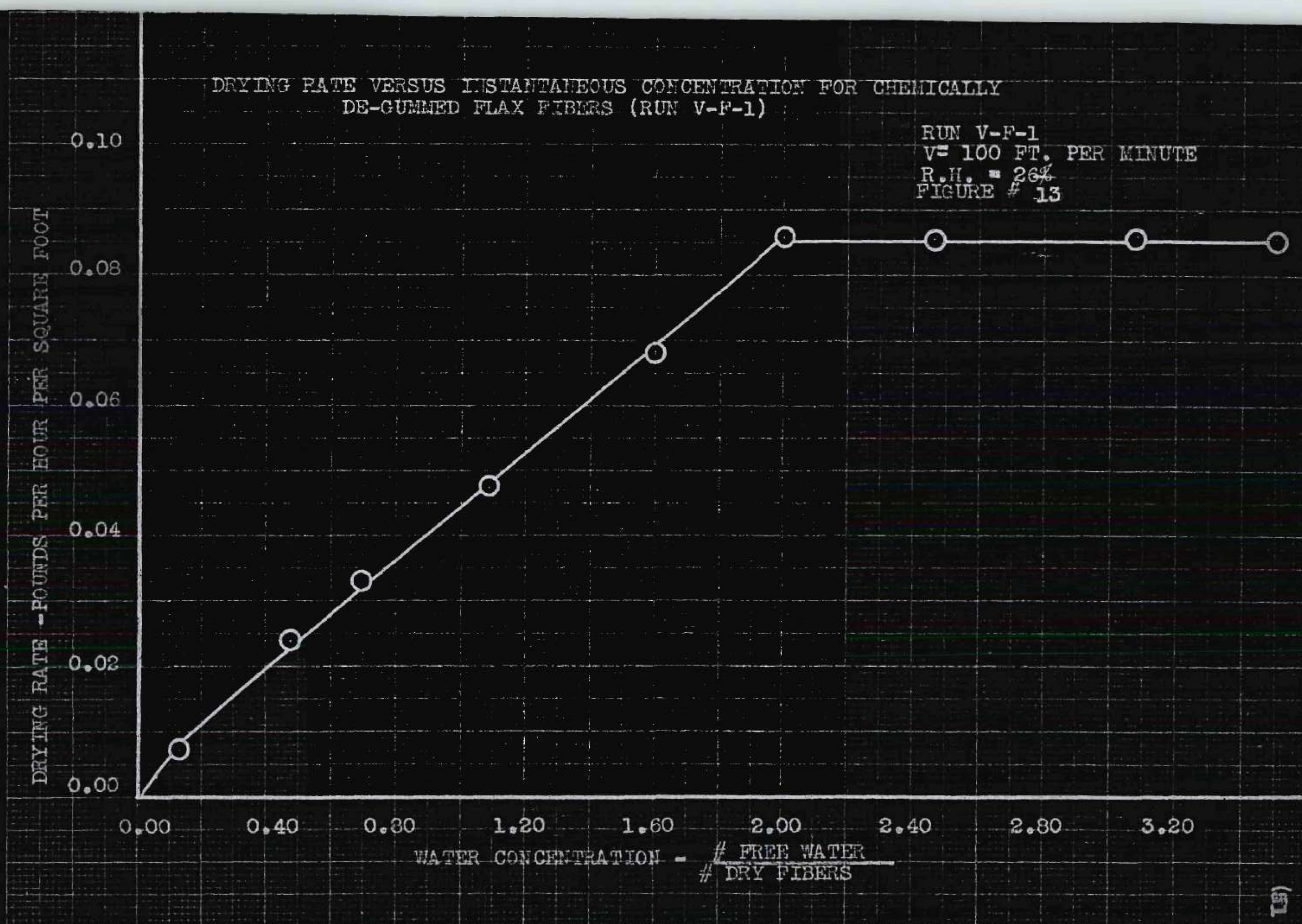
W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	#Free H_2O / #Dry Fibers
10.88	1.50	40.00	0.15	4.32	4.20	2.10
9.88	1.50	40.00	0.15	3.32	3.20	1.60
9.68	3.00	85.70	0.14	3.12	3.00	1.50
9.48	3.00	88.80	0.14	2.92	2.80	1.40
9.16	2.50	83.30	0.12	2.60	2.48	1.24
8.90	2.50	91.00	0.11	2.34	2.22	1.11
8.52	2.50	105.50	0.10	1.96	1.84	0.92
8.28	1.80	84.68	0.09	1.72	1.60	0.80
7.98	1.80	96.00	0.08	1.42	1.30	0.65
7.54	1.80	128.30	0.06	0.98	0.86	0.43
7.28	1.40	114.00	0.05	0.72	0.60	0.30
6.98	1.20	150.00	0.03	0.42	0.30	0.15

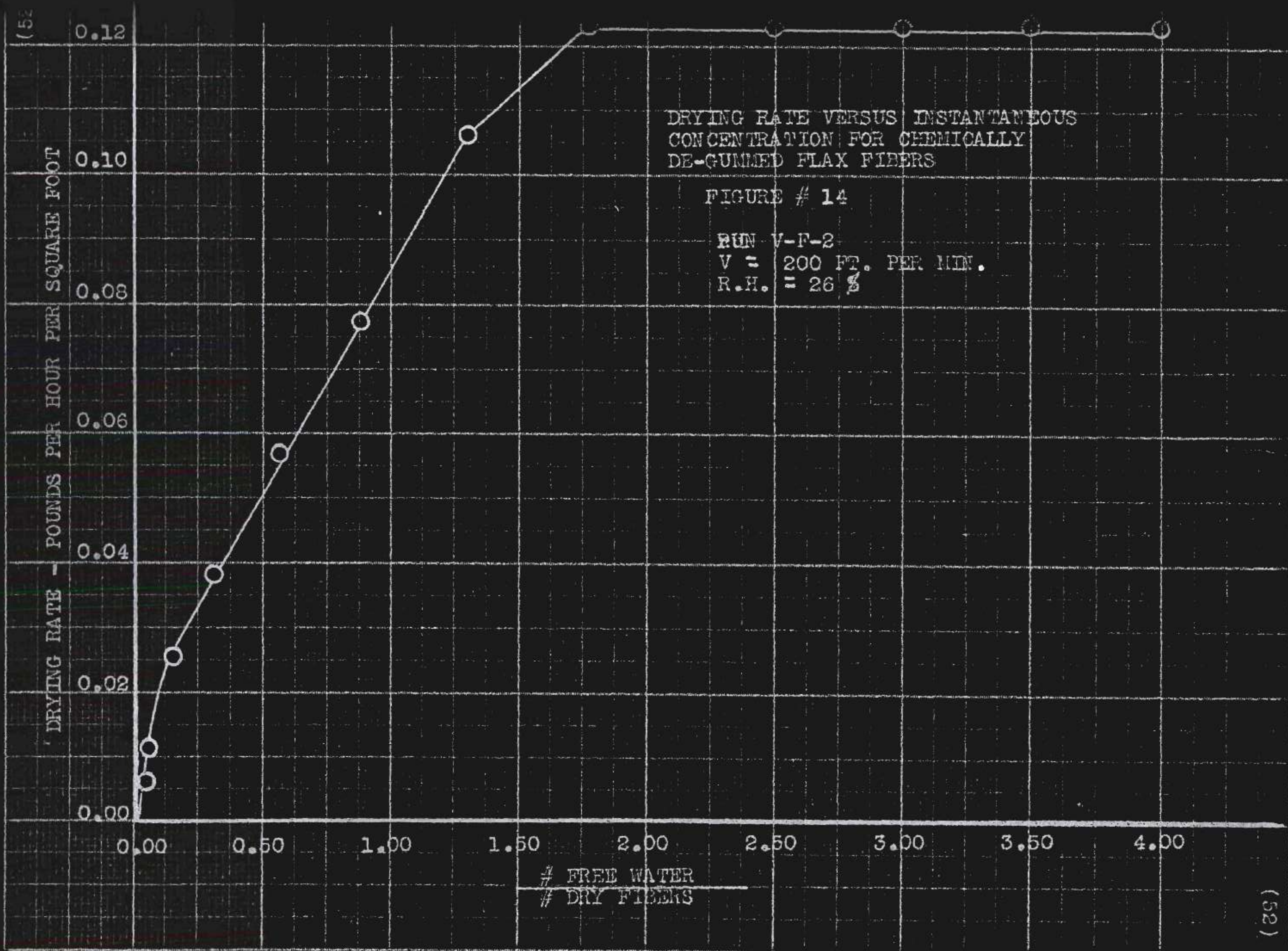
<u>Effect of Air Velocity on the Drying Rate of De-Gummed Flax Fibers.</u> In runs V-F-1, V-F-2, V-F-3, V-F-4 and V-F-5, Figures 13, 14, 15, 16, 17, 18, the dry-bulb and wet-bulb temperatures were maintained at 142°F and 102°F respectively (percent relative humidity = 25%), thickness at 3/8 inch and the air velocity was allowed to vary from 100 to 1500 feet per minute.

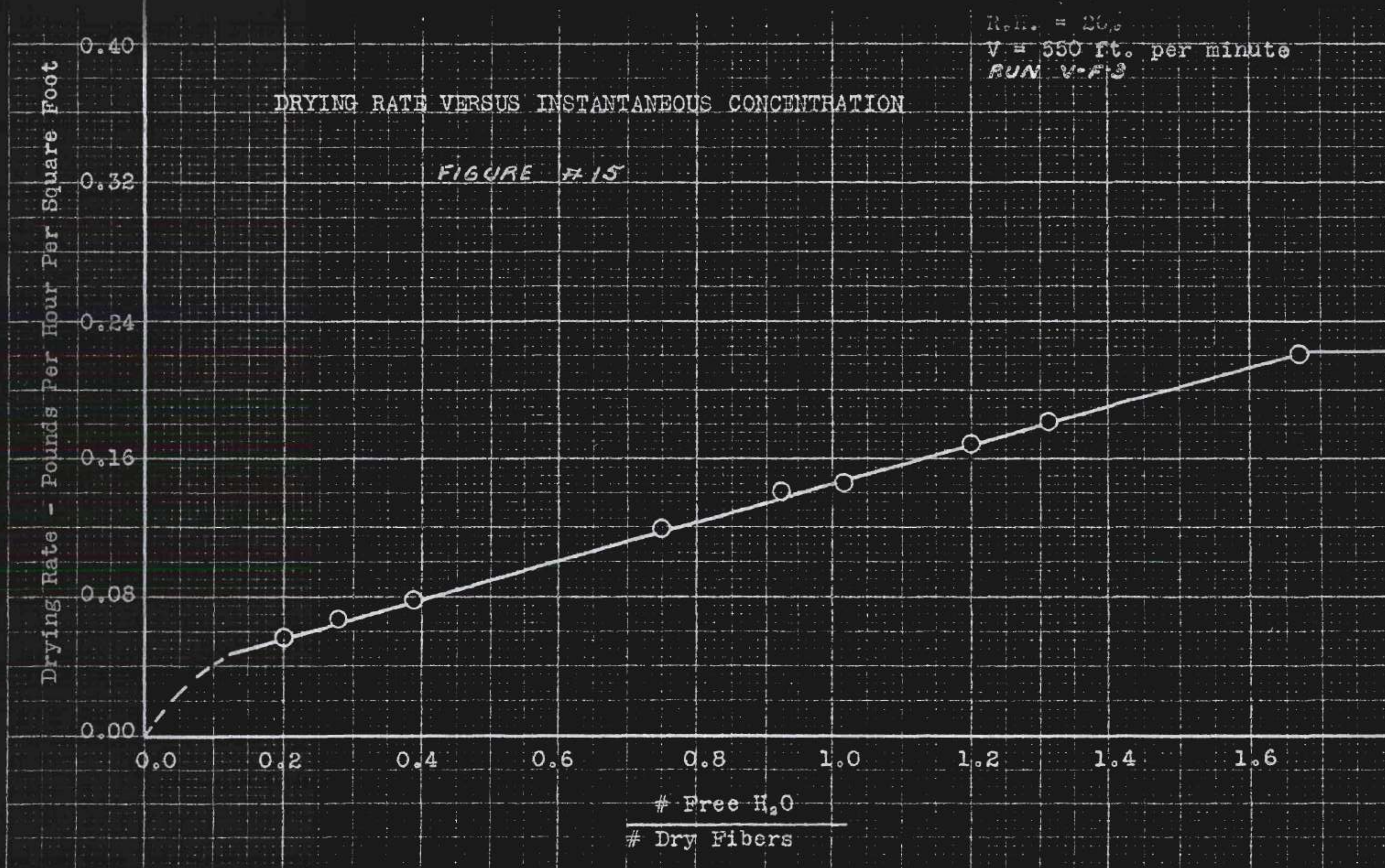
An increase in air velocity increases the coefficients of heat transfer and diffusion of the air film and this is equivalent to increasing the rate of drying during the constant-rate period in direct proportion to the increase in these film coefficients.

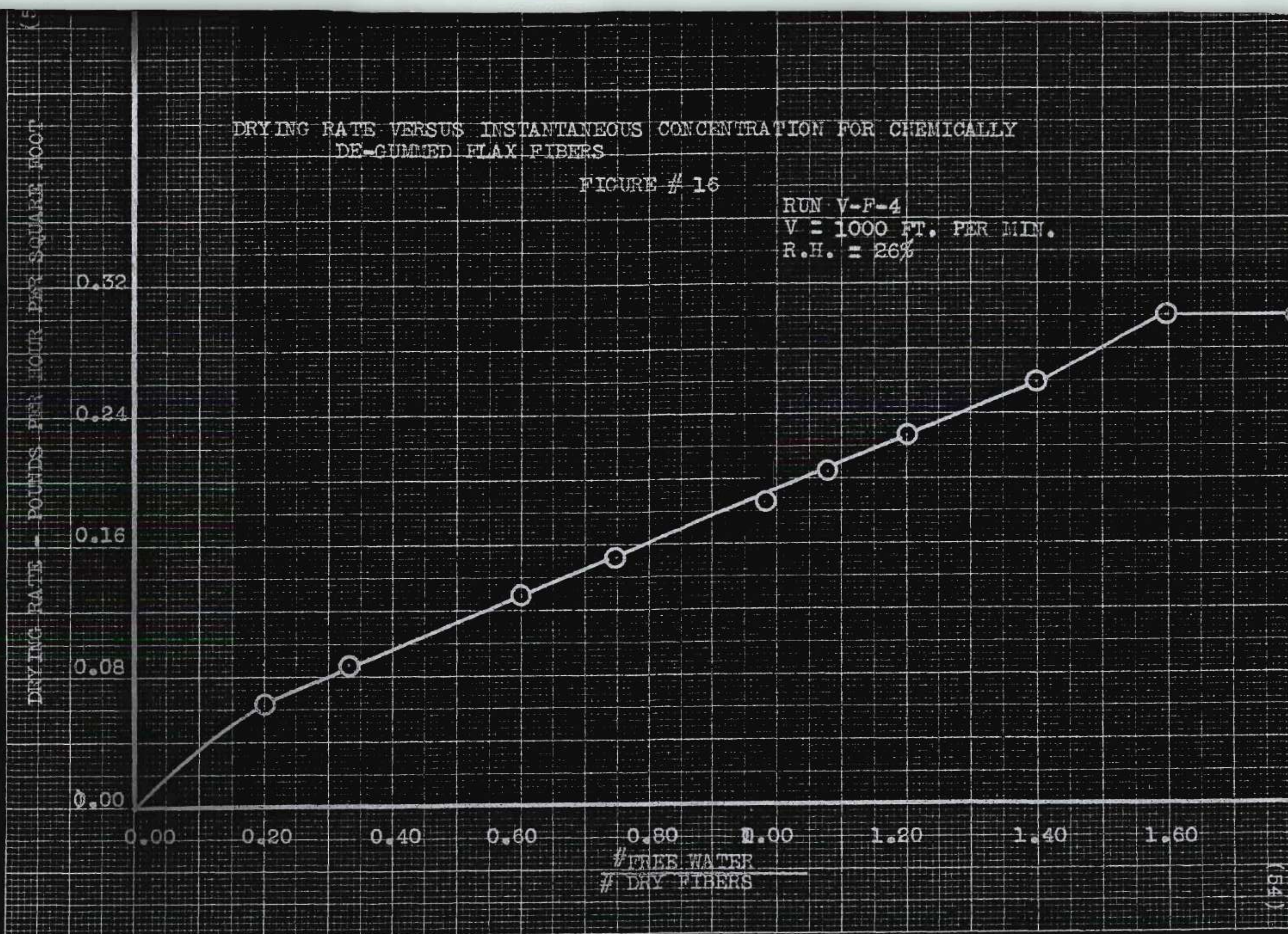
These curves show the large effect of air velocity on the drying rate through the constant-rate interval and its decreasing effect as the material approaches dryness. It is evident from these curves that air velocity has a very important effect on the drying rate of flax fibers.

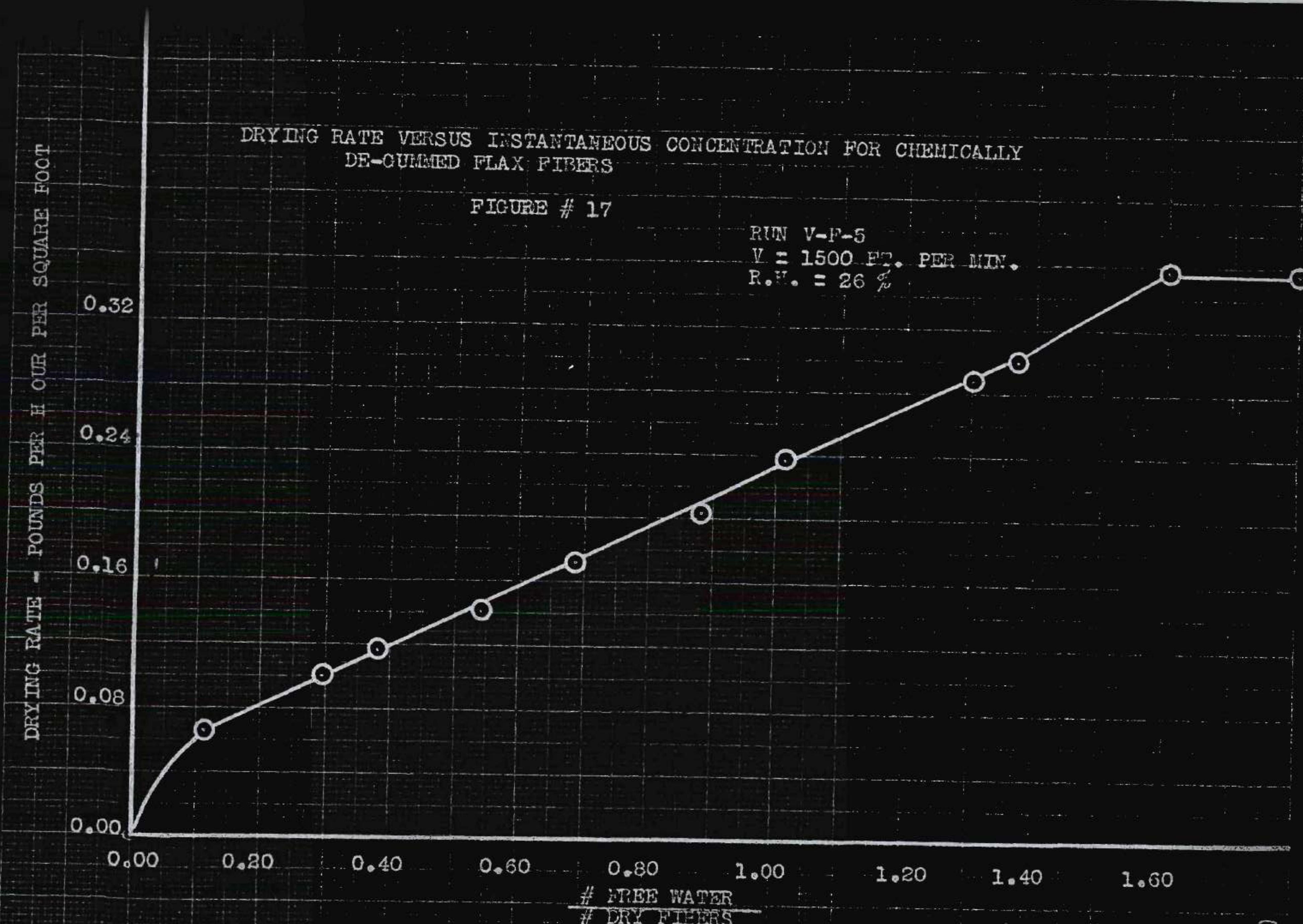
Curves 1, 2, 3 and 4 of Fig. 19 show a plot of drying rate against air velocity at different water concentrations in the fibers. Points on these curves are obtained by reading along a constant concentration line of Fig. 18. These curves readily show the decreasing effect of air velocity on drying rate as the water concentration decreases, and also suggest that the intensity of the velocity effect will decrease at high air velocities as the curves begin to flatten at the higher velocities.


DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY
DE-GUMMED FLAX FIBERS (RUN V-F-1)
RUN V-F-1
V= 100 FT. PER MINUTE
R.H. = 26%
FIGURE # 13
DRYING RATE -POUNDS PER HOUR PER SQUARE FOOT
0.10
0.08
0.06
0.04
0.02
0.00
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
WATER CONCENTRATION - # FREE WATER / # DRY FIBERS


DRYING RATE VERSUS INSTANTANEOUS
CONCENTRATION FOR CHEMICALLY
DE-GUMMED FLAX FIBERS
FIGURE # 14
RUN V-F-2
V = 200 FT. PER MIN.
R.H. = 26 %
DRYING RATE - POUNDS PER HOUR PER SQUARE FOOT
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
FREE WATER
DRY FIBERS

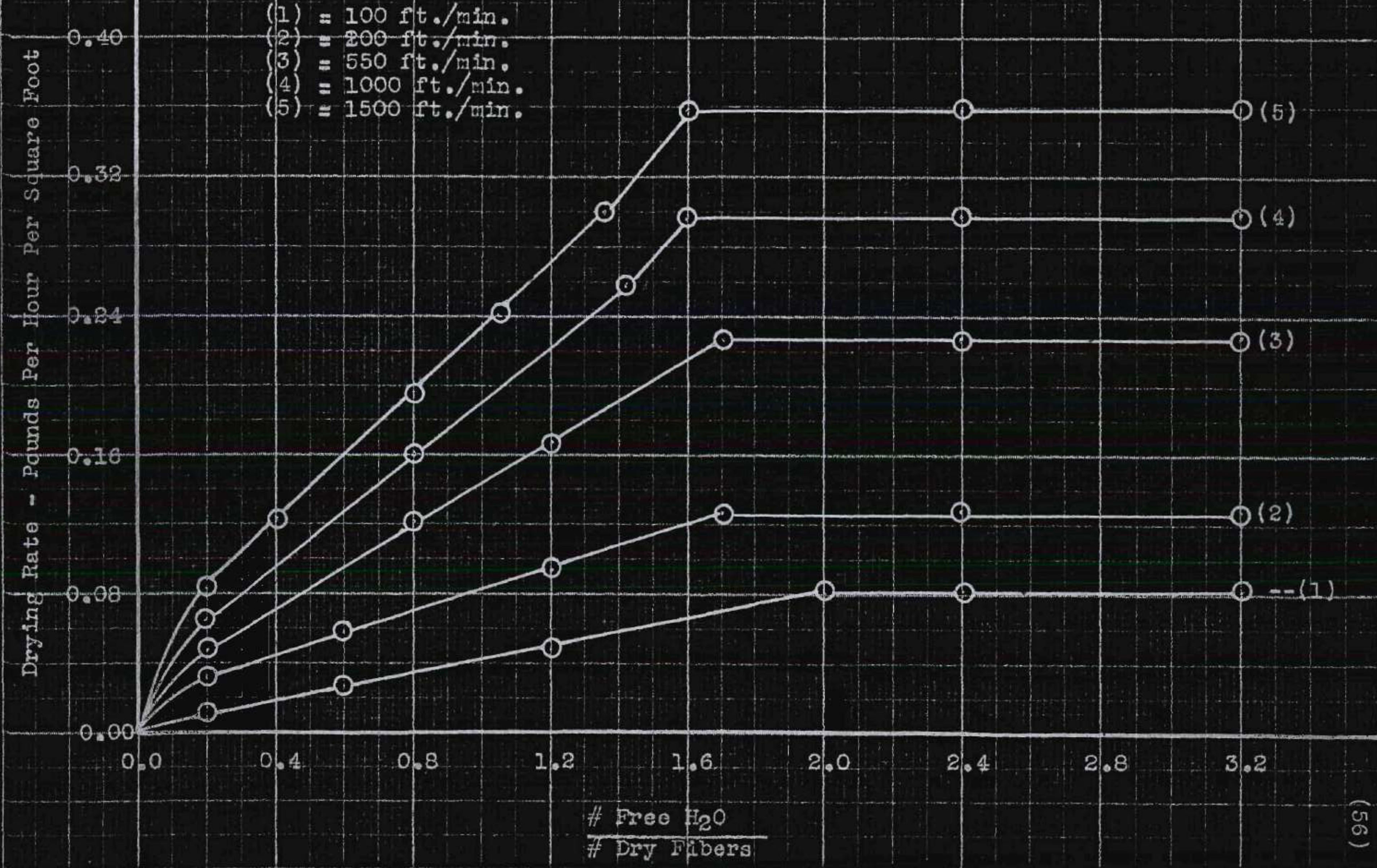

DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION
FIGURE #15
V = 550 ft. per minute
RUN V-F-3
Drying Rate - Pounds Per Hour Per Square Foot
0.40
0.32
0.24
0.16
0.08
0.00
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Free H_2O
Dry Fibers


DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS
FIGURE # 16
RUN V-F-4
V = 1000 FT. PER MIN.
R.H. = 26%
DRYING RATE - POUNDS PER HOUR PER SQUARE FOOT
0.00
0.08
0.16
0.24
0.32
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
FREE WATER / # DRY FIBERS


DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS
FIGURE # 17
RUN V-F-5
V = 1500 FT. PER MIN.
R.H. = 26 %
DRYING RATE - POUNDS PER H OUR PER SQUARE FOOT
0.32
0.24
0.16
0.08
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
FREE WATER / # DRY FIBERS

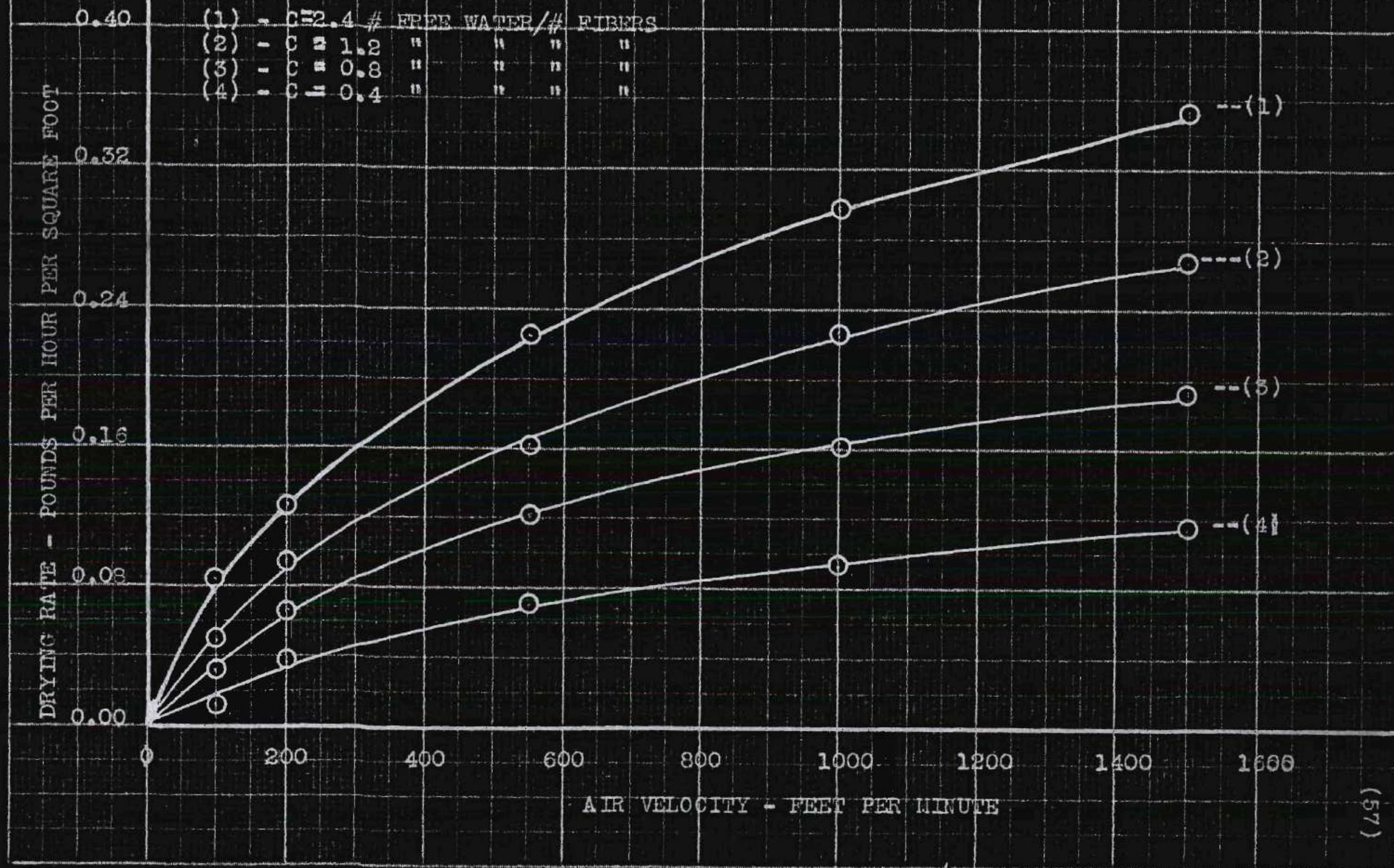
EFFECT OF AIR VELOCITY ON THE DRYING RATE OF CHEMICALLY DE-GUMMED FLAX FIBERS

FIGURE #18



FOR CHEMICALLY DE-GUMMED FLAX FIBERS

FIGURE #19



[illegible] D.B. = 142°F Thickness = 5/8" Wt. of Assembly = 4.254#
W.B. = 102°F V = 100 ft./min. Area Exposed = 15 $ft.^2$

W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	#Free H_2O / #Dry Fibers
9.60	5.60	285.00	0.09	5.20	5.16	9.75
5.50	5.60	285.00	0.09	1.10	1.06	2.00
5.45	2.32	128.00	0.07	1.05	1.01	1.90
5.30	2.62	175.00	0.06	0.89	0.86	1.62
5.03	3.85	328.00	0.05	0.63	0.59	1.11
4.81	3.20	350.00	0.03	0.41	0.37	0.70
4.70	1.35	226.00	0.02	0.30	0.26	0.49
4.57	0.75	190.00	0.02	0.17	0.13	0.24
4.50	0.37	200.00	0.01	0.10	0.06	0.11
4.48	0.24	240.00	0.01	0.08	0.04	0.07

Wt. of Assembly = 4.25# RUN V-V-2 Wt. Dry Flax = 0.77#
Equil. Water = .03# V = 200 ft./min. Drying Area = 15.00 $ft.^2$

W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	#Free H_2O / #Dry Fibers
10.60	4.35	142.50	0.12	5.58	5.55	7.25
6.38	4.35	142.50	0.12	1.36	1.33	1.73
6.05	5.00	190.50	0.11	1.03	1.00	1.30
5.73	3.90	202.50	0.08	0.71	0.68	0.89
5.51	3.00	214.50	0.06	0.48	0.45	0.59
5.31	2.15	228.00	0.04	0.29	0.26	0.34
5.17	1.51	240.00	0.03	0.15	0.12	0.16
5.10	0.50	180.00	0.01	0.08	0.05	0.07
5.08	0.25	150.00	0.01	0.06	0.03	0.04

Wt. dry flax - 211#
Wt. of Assembly = 4.56#

RUN V-F-3 V = 550 ft./min. Eq. H_2O = .05#

W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	# Free H_2O / # Dry Fibers
13.48	3.35	60.00	0.22	6.81	6.76	3.20
10.29	3.35	60.00	0.22	3.62	3.57	1.69
9.51	5.72	127.00	0.18	2.84	2.79	1.32
9.25	5.54	130.00	0.17	2.58	2.53	1.20
8.93	5.30	141.00	0.15	2.26	2.21	1.05
8.66	5.05	146.00	0.14	1.99	1.94	0.92
8.30	4.80	160.00	0.12	1.63	1.58	0.75
7.88	4.27	180.00	0.10	1.21	1.16	0.55
7.55	3.77	193.00	0.08	0.88	0.83	0.39
7.32	3.00	187.00	0.06	0.65	0.60	0.28
7.15	1.60	108.00	0.06	0.48	0.43	0.20
7.00	1.42	114.00	0.05	0.33	0.28	0.13
6.92	0.62	62.50	0.04	0.25	0.20	0.09

Eq. H_2O = .05# RUN V-F-4 V = 1000 ft./min.

Dry Flax = 2.11#
Wt. of Assembly = 4.56#

13.05	4.00	54.30	0.30	6.38	6.33	3.00
10.10	4.00	54.30	0.30	3.43	3.38	1.60
9.67	4.00	61.50	0.26	3.00	2.96	1.40
9.25	4.00	71.50	0.22	2.58	2.53	1.20
9.00	4.00	77.70	0.21	2.33	2.28	1.08
8.72	3.00	66.00	0.18	2.05	2.00	0.95
8.30	3.00	79.50	0.15	1.63	1.58	0.75
7.98	3.00	93.00	0.13	1.31	1.26	0.60
7.67	3.00	109.00	0.11	1.00	0.95	0.45
7.39	2.80	140.00	0.08	0.72	0.68	0.32

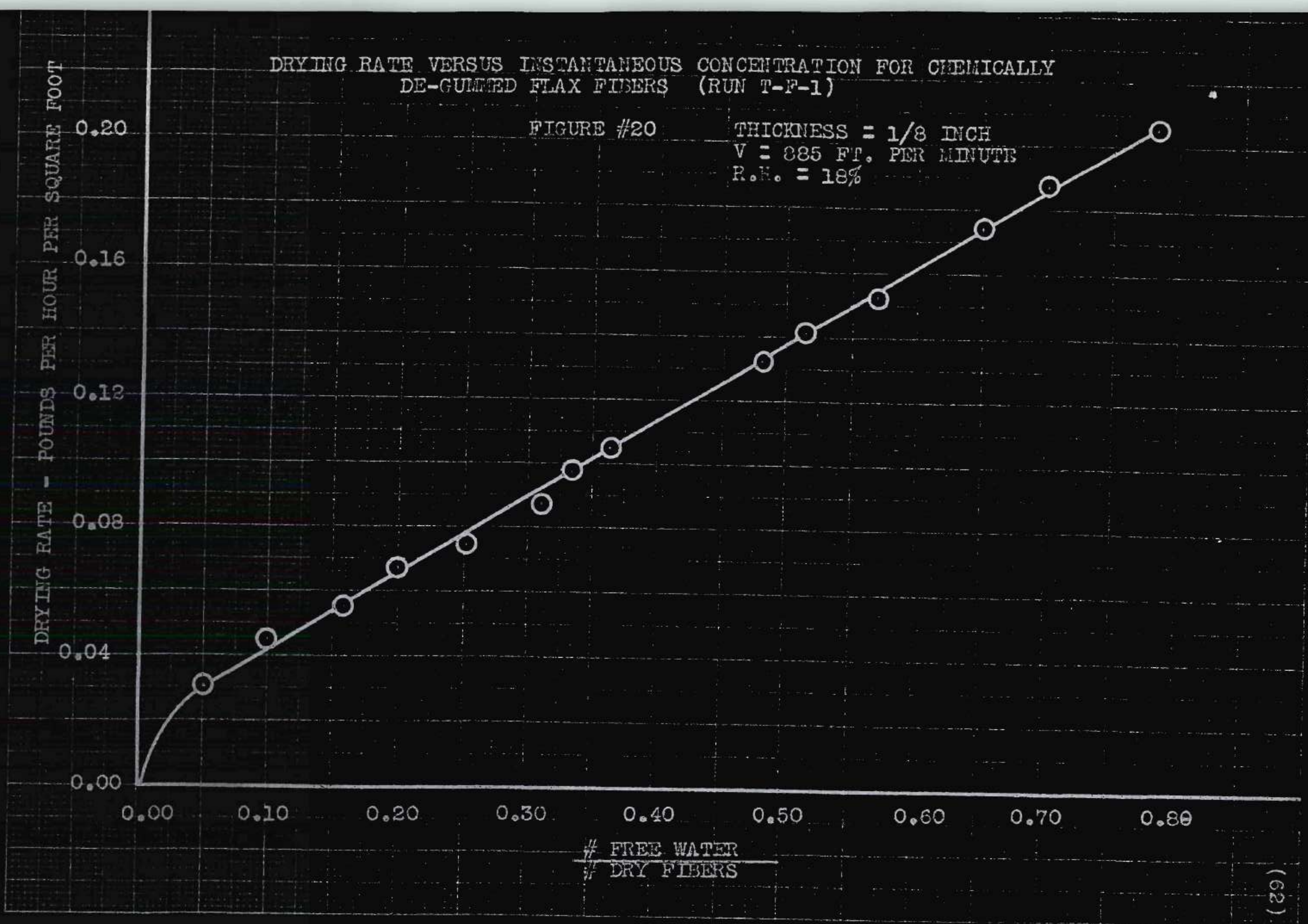
V-F-4 (cont.)

W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	# Free H_2O / # Dry Fibers
7.14	1.40	91.60	0.06	0.47	0.42	0.20
7.04	1.40	98.00	0.06	0.36	0.32	0.15
6.89	1.40	140.00	0.04	0.22	0.17	0.08

V-F-5 = H-F-2

<u>Effect of Thickness on the Drying Rate of Flax Fibers.</u> Runs T-F-1, T-F-2, T-F-3 and T-F-5, Figures 20, 21, 22, 23, 24, show the effect of thickness (depth of fiber mat leaving washing machine squeeze rolls) on the drying rate of flax fibers during the falling-rate period. The velocity was held at 885 feet per minute, and the relative humidity at 18 percent. The thickness has little or no effect during the constant rate period and the effect of varying the thickness from 1/8 to 5/8 inch does not alter the drying rate in the falling-rate interval considerably.

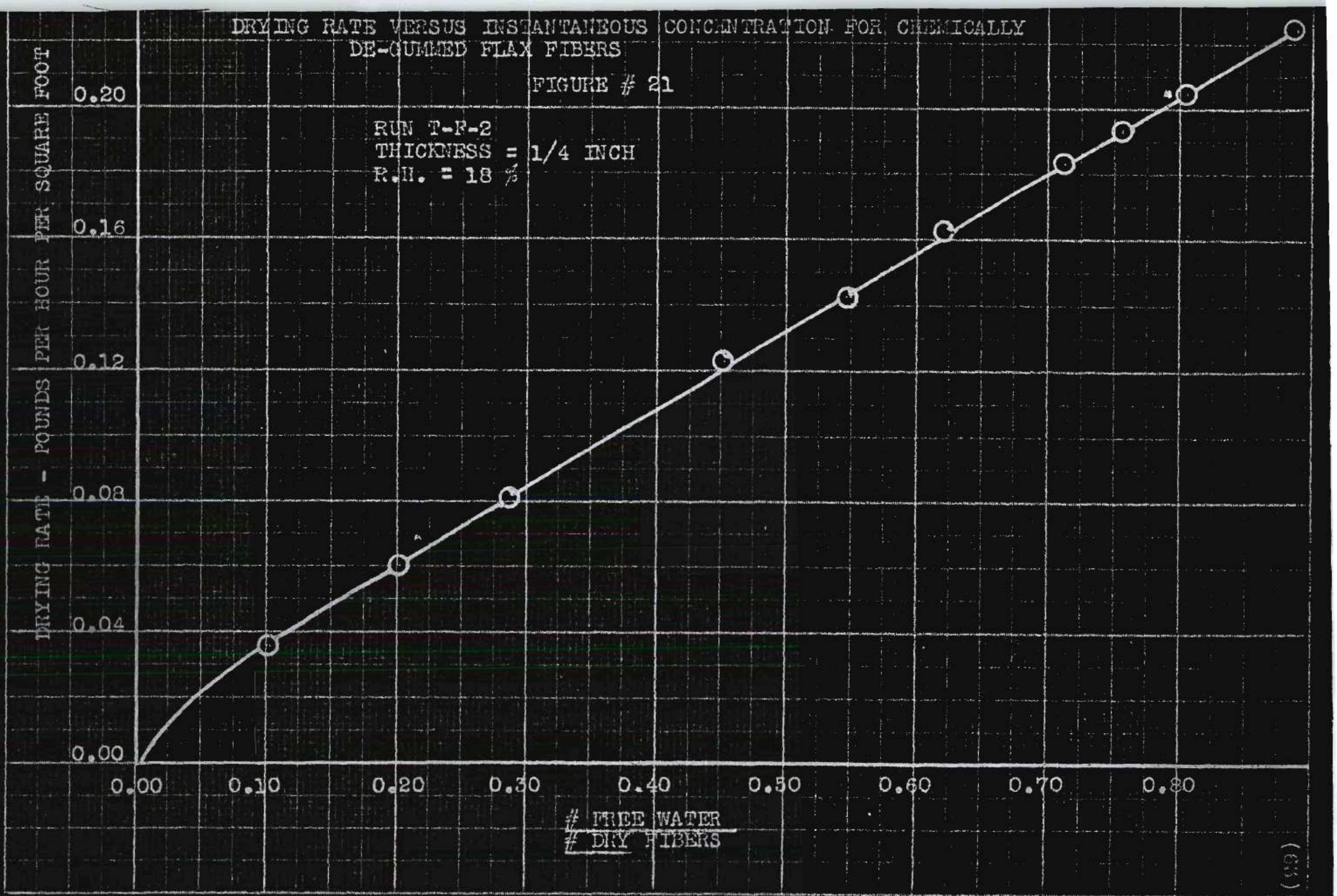
Thickness does not greatly affect the drying rate provided it does not exceed 5/8 inch.



DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS (RUN T-F-1)

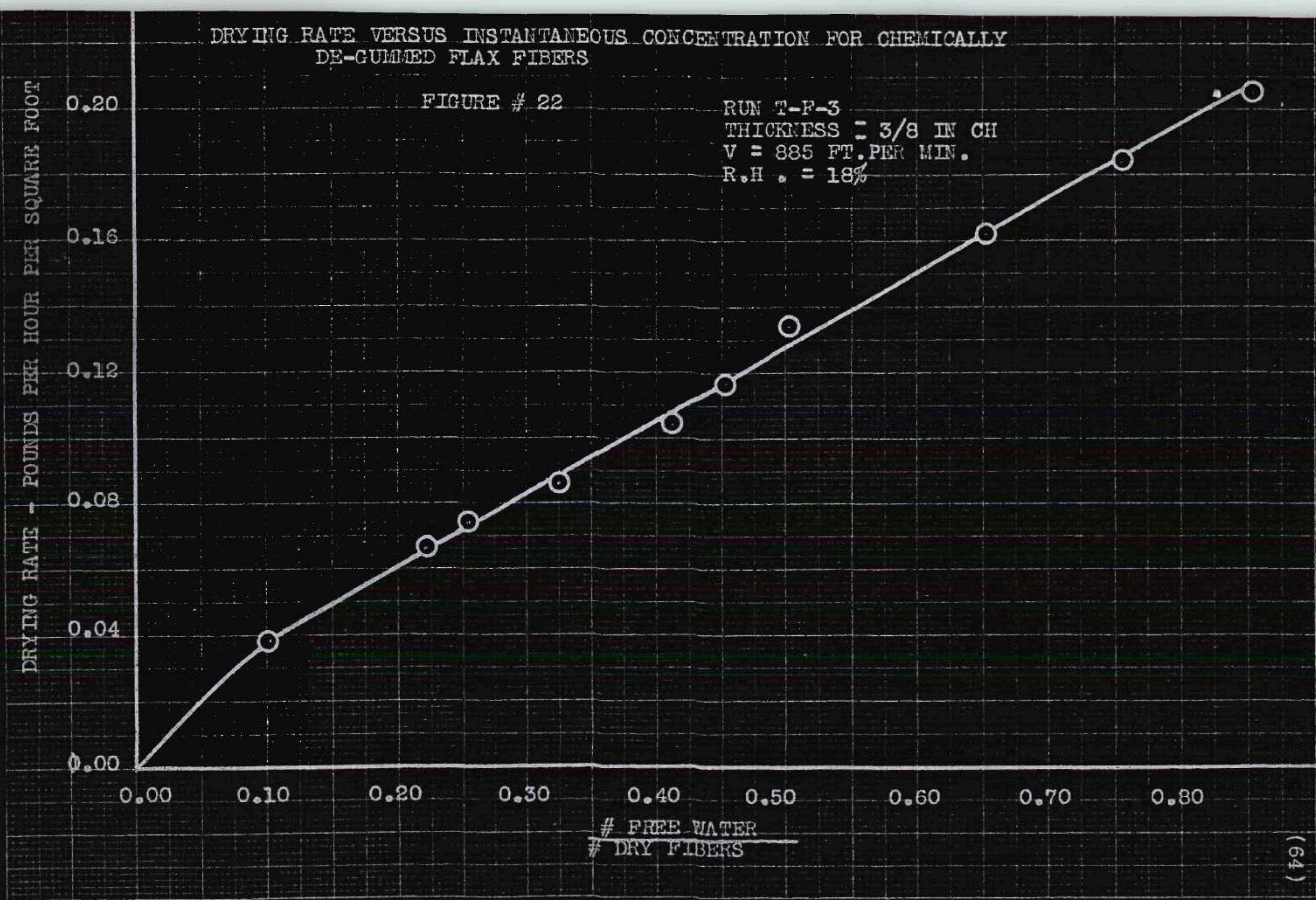
FIGURE #20

THICKNESS = 1/8 INCH
V = 885 FT. PER MINUTE
R.H. = 18%



DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS

FIGURE # 21

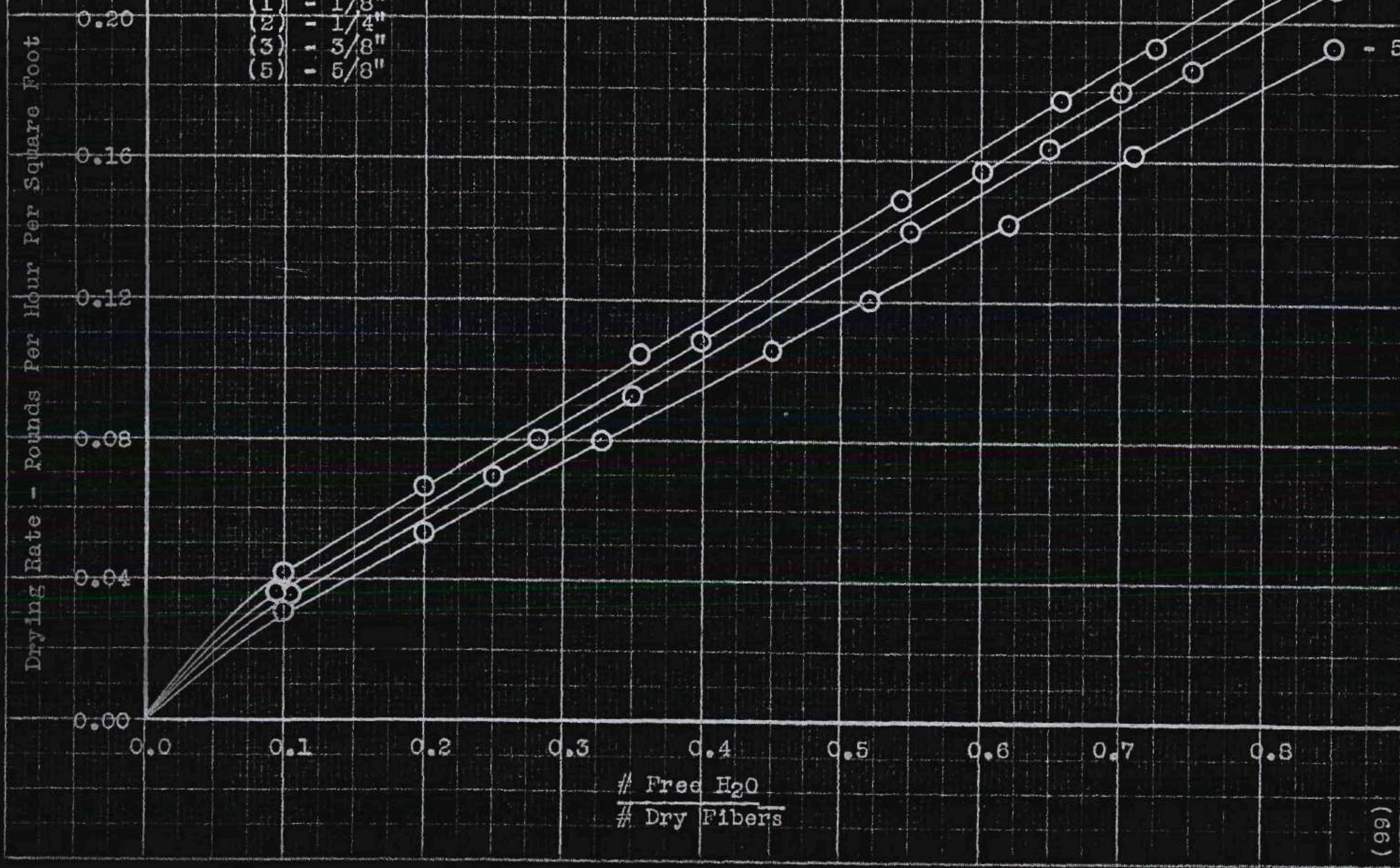

DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS
FIGURE # 22
RUN T-F-3
THICKNESS = 3/8 IN CH
V = 885 FT. PER MIN.
R.H. = 18%
DRYING RATE - POUNDS PER HOUR PER SQUARE FOOT
0.00
0.04
0.08
0.12
0.16
0.20
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
FREE WATER / # DRY FIBERS

DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR CHEMICALLY DE-GUMMED FLAX FIBERS

FIGURE # 23

EFFECT OF THICKNESS ON THE DRYING RATE OF CHEMICALLY DE-GUMMED FIBERS

FIGURE #24



RUN T-F-1
D.B. = 165°F
W.B. = 110°F

R.H. = 18%
V = 885 ft./min.
Thickness = 1/8"

Weight of Assembly = 5.00#
#Dry Flax = 0.91#
Eq. H_2O = .027#

W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	#Free H_2O / #Dry Fibers
6.65	0.62	12.00	0.21	0.74	0.71	0.78
6.58	0.61	13.20	0.19	0.66	0.64	0.70
6.53	0.60	14.00	0.17	0.62	0.60	0.65
6.46	0.59	15.60	0.15	0.55	0.52	0.57
6.40	0.58	16.60	0.14	0.49	0.46	0.51
6.38	0.57	17.00	0.13	0.46	0.44	0.48
6.27	0.53	19.50	0.11	0.36	0.33	0.36
6.24	0.50	20.20	0.10	0.33	0.30	0.33
6.22	0.47	21.20	0.09	0.31	0.28	0.31
6.17	0.44	22.50	0.08	0.25	0.23	0.25
6.12	0.40	23.20	0.07	0.21	0.18	0.20
6.08	0.35	24.50	0.06	0.17	0.15	0.16
6.03	0.28	24.80	0.05	0.12	0.09	0.10
5.94	0.17	23.00	0.03	0.07	0.05	0.05
5.97	0.06	15.00	0.02	0.05	0.02	0.02

Weight of Assembly = 5.00# RUN - T-F-2 Thickness = 2/8" Eq. H_2O = .04#
Dry Flax = 1.41 #

8.01	1.46	22.50	0.26	1.60	1.56	1.11
7.93	1.44	23.00	0.25	1.52	1.48	1.05
7.79	1.42	23.70	0.24	1.38	1.34	0.95
7.75	1.41	24.20	0.23	1.34	1.30	0.92
7.69	1.40	25.50	0.22	1.28	1.24	0.88
7.58	1.36	27.00	0.20	1.17	1.13	0.80
7.51	1.34	28.00	0.19	1.10	1.06	0.75

RUN T-F-2 (cont.)

W lbs.	ΔW lbs.	ΔT min.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	#Free H_2O / #Dry Fibers
7.45	1.30	29.00	0.18	1.04	1.00	0.71
7.32	1.22	31.20	0.16	0.91	0.87	0.62
7.21	1.13	33.00	0.14	0.80	0.76	0.54
7.08	1.03	35.20	0.12	0.67	0.63	0.45
6.84	0.84	40.00	0.08	0.43	0.39	0.28
6.73	0.65	45.00	0.06	0.32	0.28	0.20

Wt. of Assembly = 5.00# RUN T-F-3 Thickness = 3/8" Eq. H_2O = .07#
Dry Flax = 2.31#

9.96	2.20	34.00	0.26	2.65	2.58	1.12
9.76	2.20	38.00	0.23	2.45	2.38	1.03
9.34	2.00	38.70	0.21	2.03	1.96	0.85
9.11	1.80	39.50	0.18	1.80	1.73	0.75
8.88	1.60	40.00	0.16	1.57	1.50	0.65
8.53	1.40	42.50	0.13	1.22	1.15	0.50
8.42	1.20	41.50	0.12	1.11	1.04	0.45
8.33	1.00	37.50	0.11	1.02	0.95	0.41
8.12	0.80	37.00	0.09	0.81	0.74	0.32
7.96	0.40	22.00	0.07	0.65	0.58	0.25
7.89	0.80	48.00	0.07	0.58	0.51	0.22

RUN T-F-5 Thickness = 5/8"

Wt. dry Flax = 3.34#
Wt. of assembly = 5.00#

W Lbs.	ΔW lbs.	ΔT lbs.	Rate #/hr./sq.ft.	Total H_2O lbs.	Free H_2O lbs.	#Free H_2O / #Dry Fibers
12.27	2.40	41.50	0.23	3.93	3.83	1.14
11.84	2.20	40.00	0.22	3.50	3.40	1.01
11.53	2.00	39.00	0.21	3.19	3.09	0.92
11.23	1.80	39.50	0.19	2.89	2.79	0.83
11.06	1.60	36.00	0.18	2.72	2.62	0.78
10.69	2.40	63.50	0.15	2.35	2.25	0.67
10.56	2.30	65.00	0.14	2.22	2.12	0.63
10.29	1.00	31.50	0.13	1.95	1.85	0.55
10.12	2.10	72.00	0.12	1.78	1.68	0.50
9.95	2.00	74.00	0.11	1.61	1.51	0.45
9.55	1.80	88.00	0.08	1.21	1.11	0.33
9.35	1.60	89.00	0.07	1.01	0.91	0.27
9.21	1.20	75.00	0.06	0.87	0.77	0.23

VI EFFECT OF OPERATING VARIABLES ON DRYING RATE OF WATER-RETTED WHOLE FLAX STRAW

Effect of Humidity on Straw.

Discussion of Results:

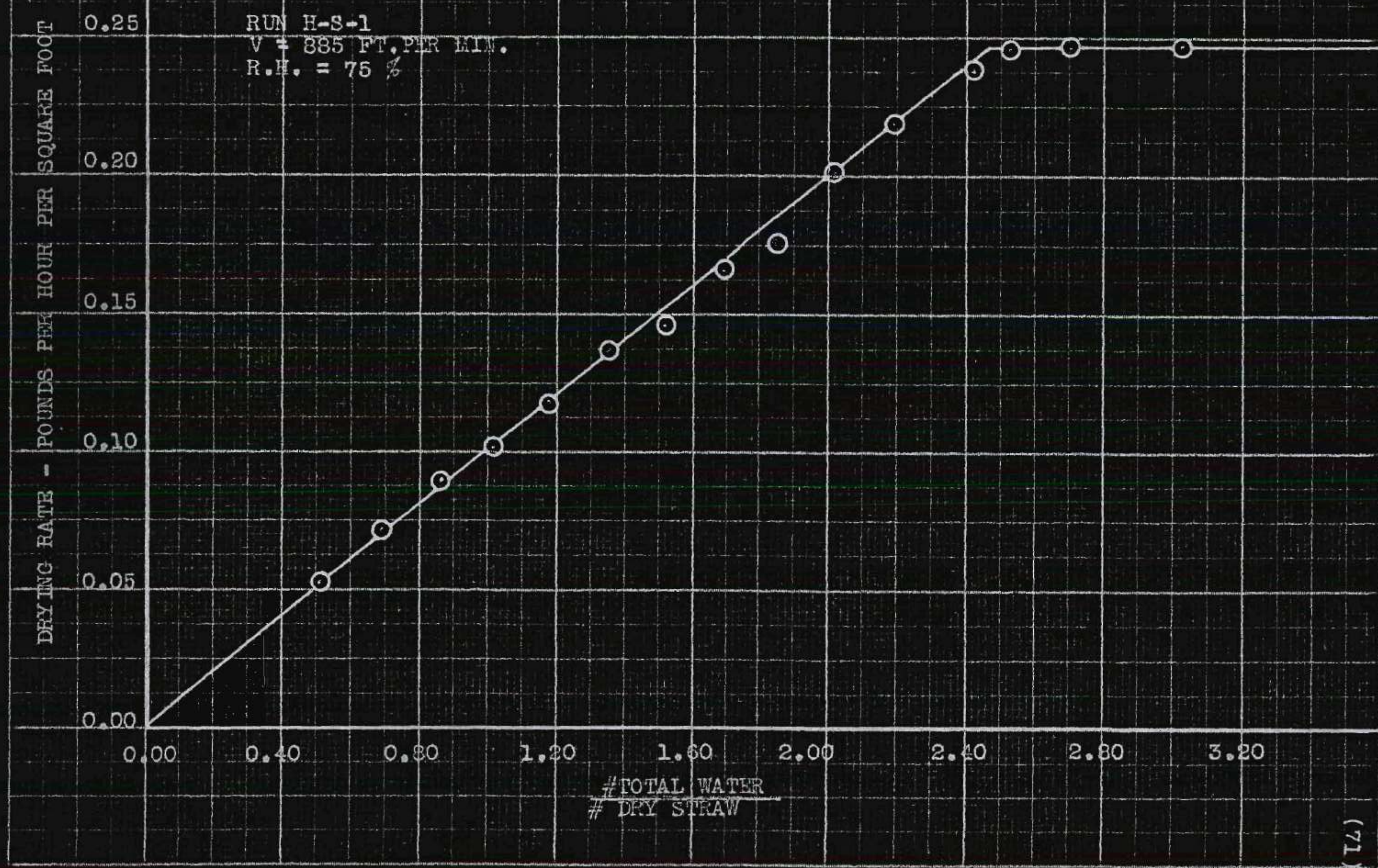
Runs H-S-1, H-S-2, H-S-3 and H-S-5, Figures 25, 26, 27, 28 establish the effect of humidity on the drying rate of flax straw. Curves on Figure 29 are plotted by taking points directly from the preceding graphs while the runs plotted individually show the actual calculated points for the rate curve.

Air humidity has a similar effect on the drying rate of flax straw as it does on the flax fibers. All runs were made at a constant wet-bulb temperature of 100^{o}F and an air velocity of 885 feet per minute. The bulk density of the straw was approximately 0.70 pounds per cubic foot for all runs.

For illustration of sample calculation of drying rates see page 38.

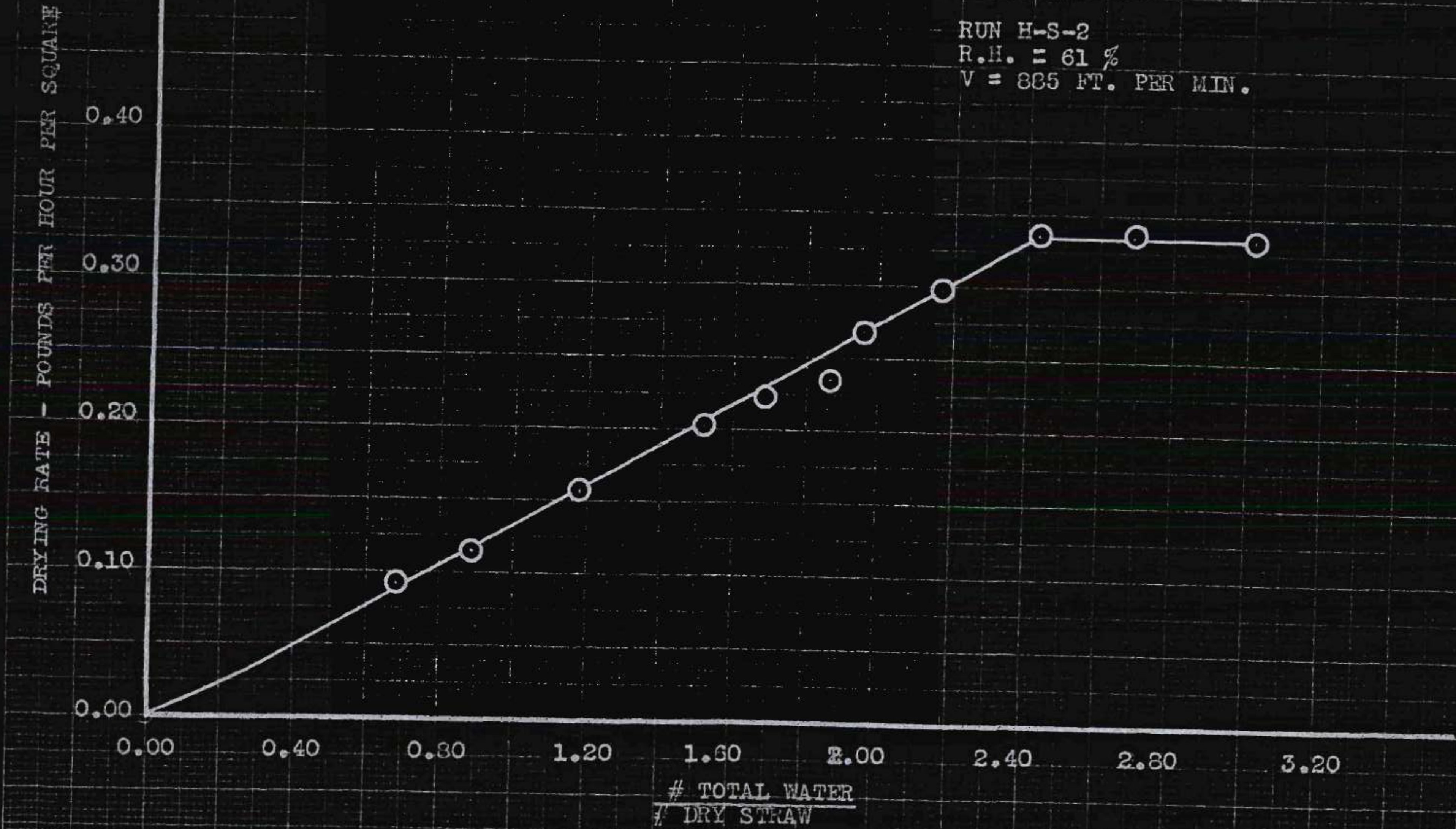
DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER-RETTED FLAX STRAW

FIGURE # 25



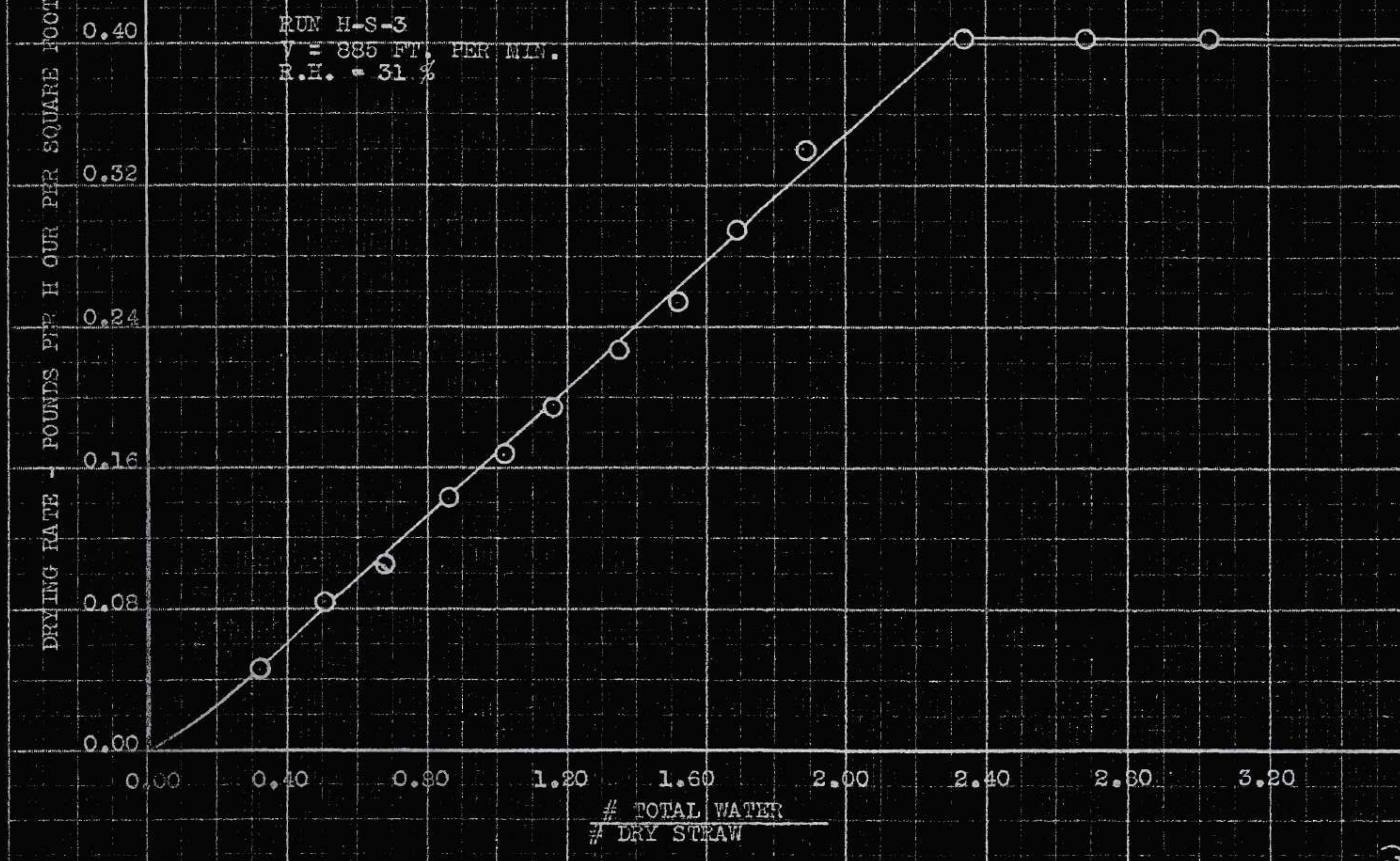
DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER-RETTED FLAX STRAW

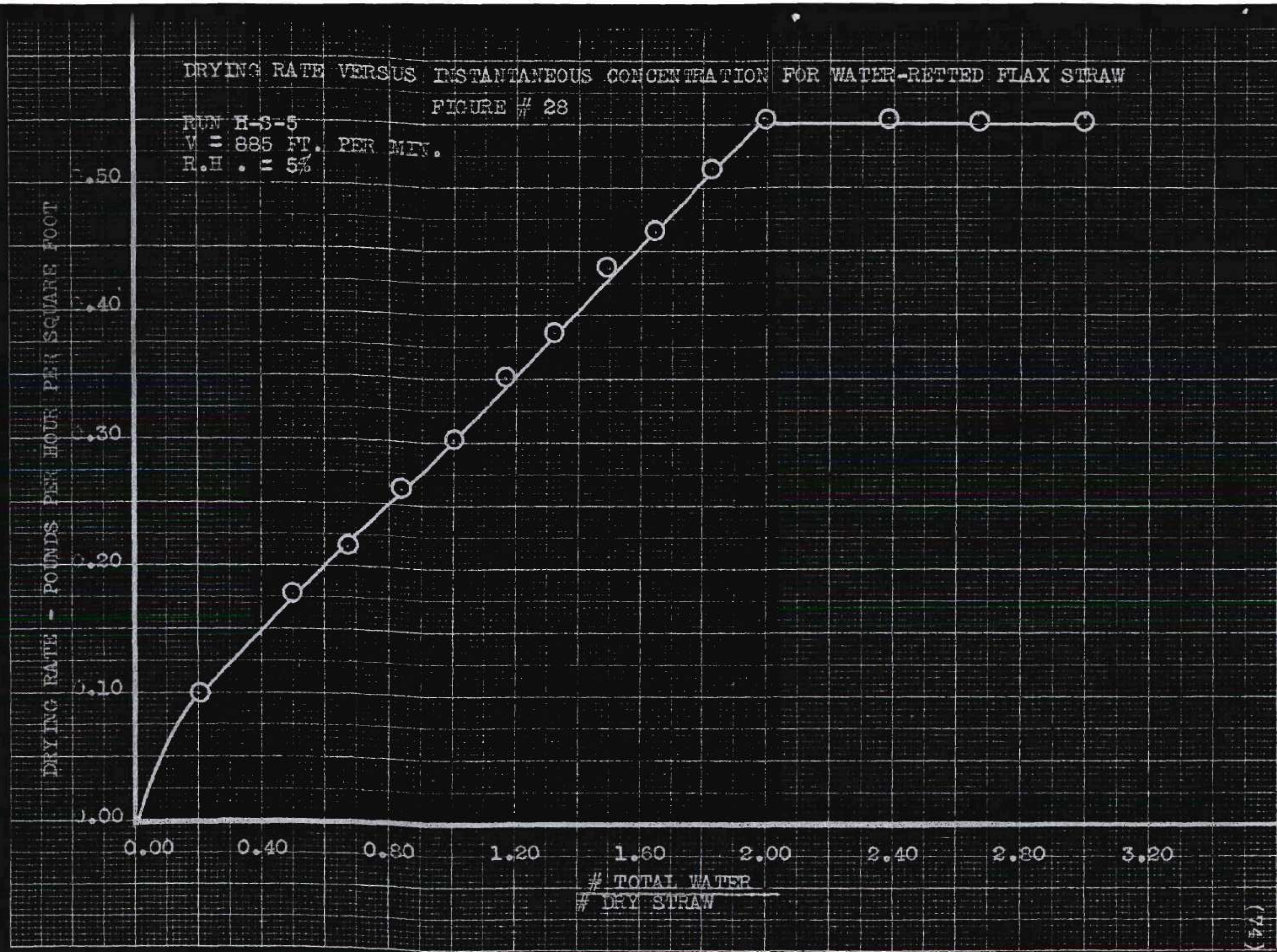
FIGURE # 26

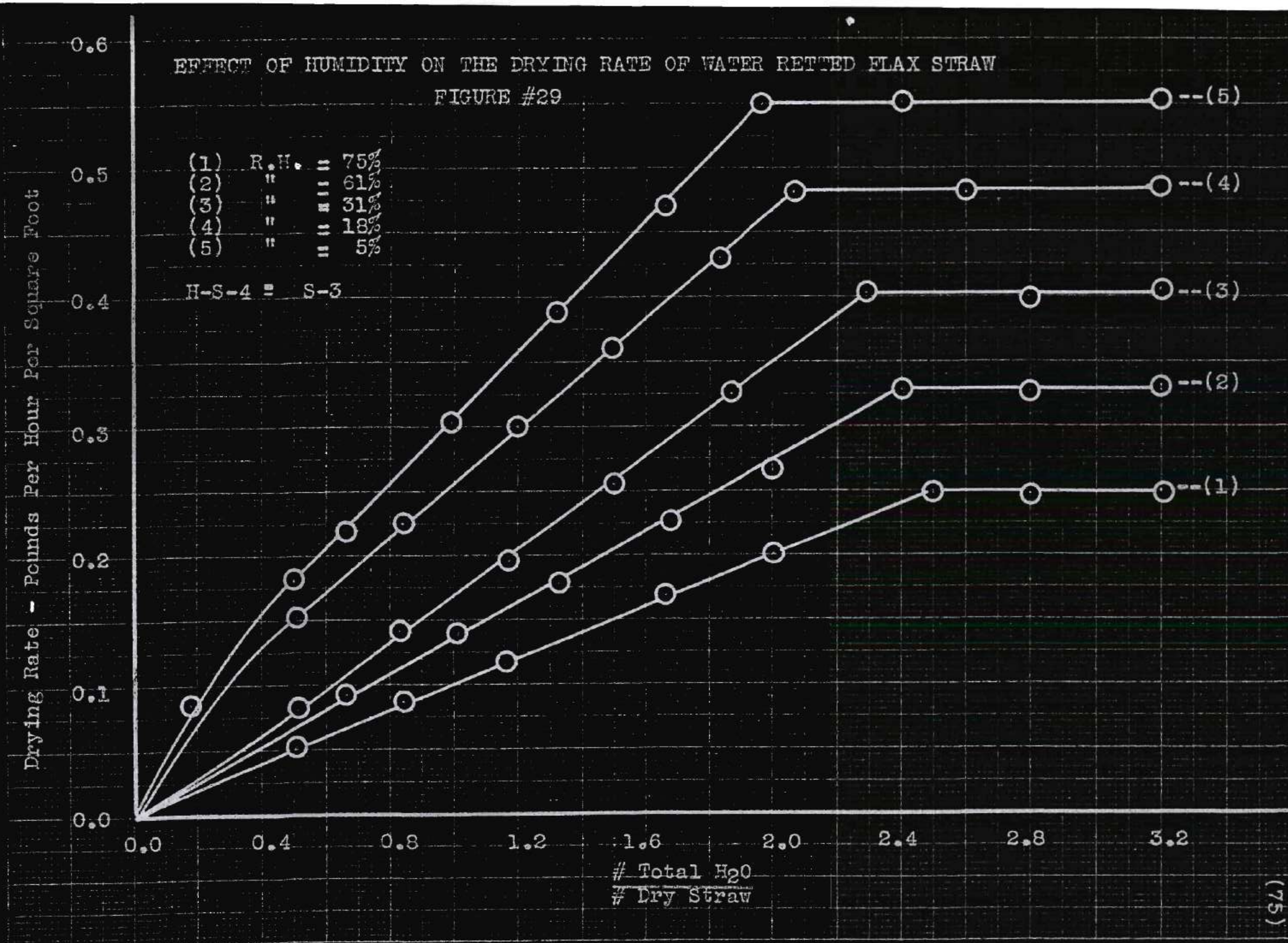


DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER-RETTED FLAX STRAW

FIGURE # 27




DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER-RETTED FLAX STRAW
FIGURE # 28
RUN H-S-5
V = 885 FT. PER MIN.
R.H. = 5%
DRYING RATE - POUNDS PER HOUR PER SQUARE FOOT
.50
.40
.30
.20
.10
.00
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
TOTAL WATER / # DRY STRAW



EFFECT OF HUMIDITY ON THE DRYING RATE OF WATER RETTED FLAX STRAW

FIGURE #29

EFFECT OF HUMIDITY ON STRAW

D.B. = 108°F
W.B. = 100°F

V = 885 ft./min.
Bulk Density = $\frac{0.70\#}{cu.ft.}$

Wt. of Assembly = 5.00#
Dry Straw = 1.50#

Run H-S-1 % R.H. = 75%

W lbs.	ΔW lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	#Total H_2O / # Dry Straw
11.00	1.00	16.30	0.25	4.50	3.00
10.50	1.00	16.30	0.25	4.00	2.67
10.25	1.00	16.30	0.25	3.75	2.50
10.00	2.00	33.30	0.24	3.50	2.40
9.75	2.00	37.20	0.22	3.25	2.17
9.50	2.00	40.00	0.20	3.00	2.00
9.25	2.00	45.70	0.18	2.75	1.83
9.00	2.00	50.00	0.16	2.50	1.67
8.75	2.00	55.10	0.15	2.25	1.50
8.50	1.60	45.70	0.14	2.00	1.33
8.25	1.60	53.40	0.12	1.75	1.17
8.00	1.60	64.00	0.10	1.50	1.00
7.75	0.90	40.00	0.09	1.25	0.83
7.50	0.70	40.00	0.07	1.00	0.67
7.25	0.50	40.00	0.05	0.75	0.50

W.B. = 100°F
R.H. = 61%

RUN H-S-2
D.B. = 114°F

Weight of Assembly = 5.00#
Dry Straw = 1.50#

11.00	1.00	12.20	0.33	4.50	3.00
10.50	1.00	12.20	0.33	4.00	2.67
10.25	1.00	12.20	0.33	3.75	2.50
10.00	1.00	12.20	0.33	3.50	2.34
9.75	1.00	12.20	0.30	3.25	2.17

RUN H-S-2 (cont.)

W lbs.	Δ W lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	# Total H_2O / # Dry Straw
9.50	3.13	52.50	0.28	3.00	2.00
9.25	3.12	55.00	0.23	2.75	1.83
9.00	3.00	57.00	0.22	2.50	1.67
8.75	2.35	50.00	0.20	2.25	1.50
8.50	2.22	51.00	0.17	2.00	1.33
8.25	2.02	52.00	0.15	1.75	1.17
8.00	2.35	66.00	0.14	1.50	1.00
7.75	1.98	68.00	0.12	1.25	0.83
7.50	1.71	70.00	0.10	1.00	0.67

RUN H-S-3
D.B. = 134°F
W.B. = 100°F
R.H. = 31%
Wt. of Assembly = 5.00#
Wt. Dry Straw = 1.50#

11.00	1.00	10.00	0.40	4.50	3.00
10.50	1.00	10.00	0.40	4.00	2.67
10.00	1.00	10.00	0.40	3.50	2.34
9.25	2.00	24.00	0.33	2.75	1.88
9.00	3.50	48.00	0.29	2.50	1.67
8.75	3.30	52.00	0.25	2.25	1.50
8.50	3.12	55.00	0.23	2.00	1.33
8.25	2.88	59.00	0.20	1.75	1.17
8.00	2.60	64.00	0.16	1.50	1.00
7.75	2.35	67.00	0.14	1.25	0.83
7.50	2.00	72.00	0.11	1.00	0.67
7.25	1.60	77.00	0.08	0.75	0.50
7.00	1.00	80.00	0.05	0.50	0.33

RUN H-S-4 = S + 3 D.B. = 150°F
W.B. = 100°F R.H. = 18%

RUN H-S-5 W.B. = 100°F Wt. of Assembly = 5.00#
D.B. = 178°F R.H. = 5% Wt. Dry Straw = 1.50#

W lbs.	ΔW lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	# Total H_2O / # Dry Straw
11.00	1.00	7.18	0.55	4.50	3.00
10.50	1.00	7.18	0.55	4.00	2.67
10.25	1.00	7.18	0.55	3.75	2.50
10.00	1.00	7.18	0.55	3.50	2.40
9.75	1.00	7.18	0.55	3.25	2.17
9.50	1.00	7.18	0.55	3.00	2.00
9.25	2.22	17.20	0.52	2.75	1.83
9.00	3.42	29.10	0.47	2.50	1.67
8.75	3.20	29.40	0.44	2.25	1.50
8.50	3.00	30.80	0.39	2.00	1.33
8.25	2.72	31.10	0.35	1.75	1.17
8.00	2.51	33.40	0.30	1.50	1.00
7.75	1.80	27.20	0.27	1.25	0.83
7.50	1.40	26.00	0.22	1.00	0.67
7.25	1.20	26.70	0.18	0.75	0.50

Effect of Velocity on Drying Rate of Straw.

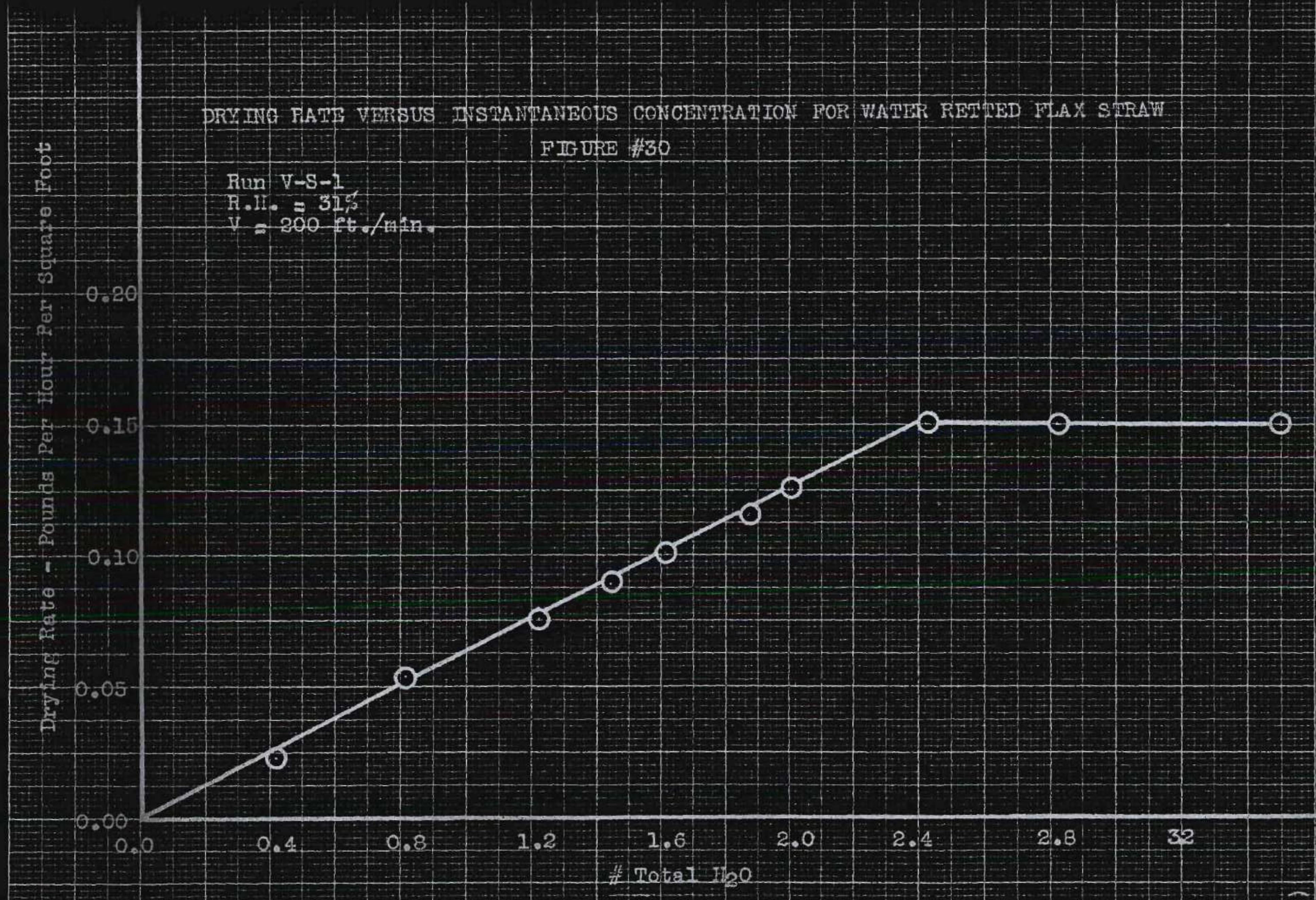
Discussion of Results:

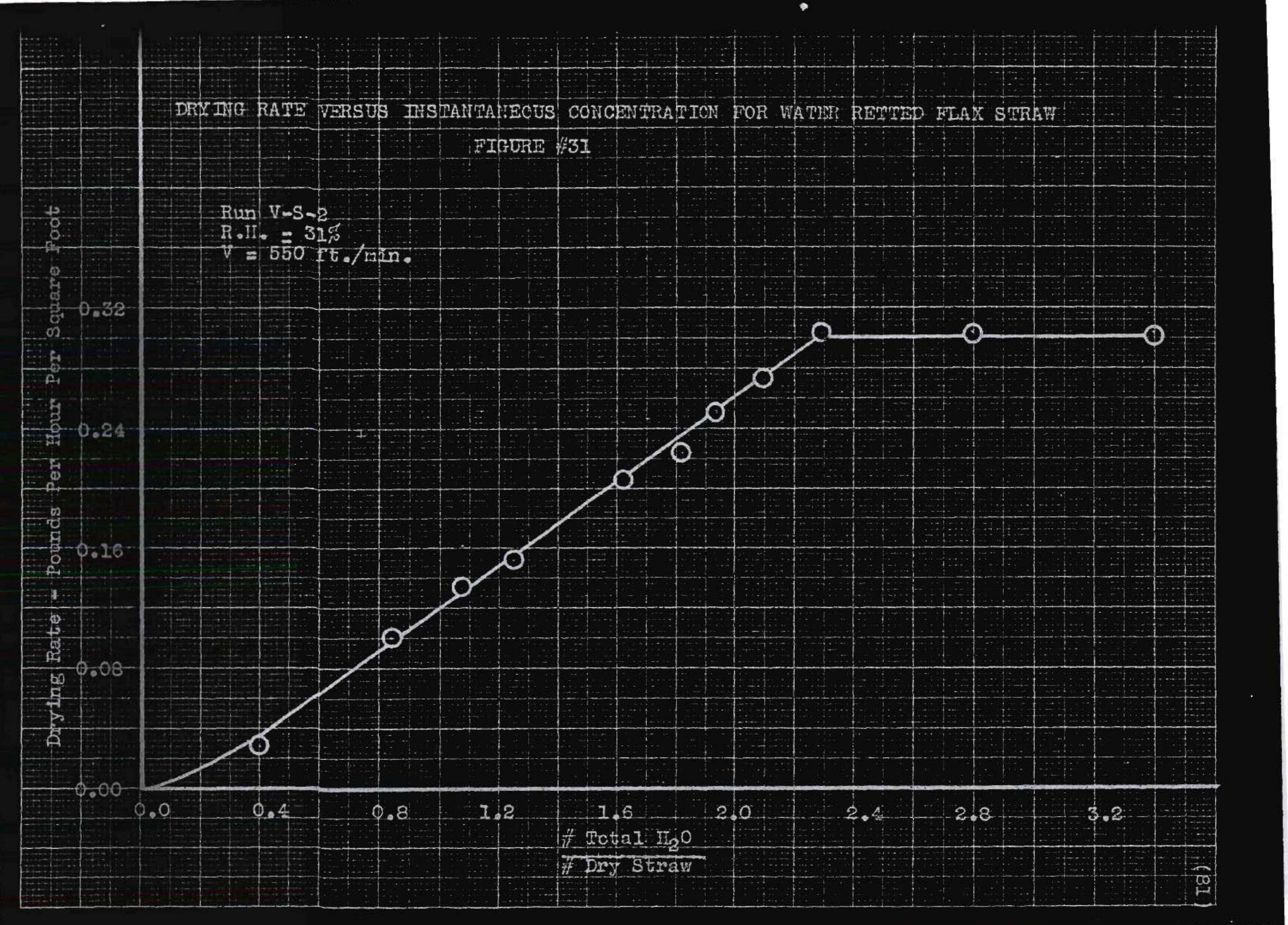
Runs V-S-1, V-S-2, V-S-3 and V-S-4, Figures 30, 31, 32, 27, 33, were made at a constant air humidity (D.B. = 134°F, W.B. = 100°F, R.H. = 31%) and bulk density (0.70 #/cu.ft.) with air velocities ranging from 200 to 1500 feet per minute. Velocity has a large effect on the drying rate during the constant-rate period, this effect diminishing as the material approaches dryness.

Figure 34 shows the rate of drying plotted against air velocities at constant moisture concentrations, the general shape of the curves being the same as those for the fibers.

DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER RETTED FLAX STRAW

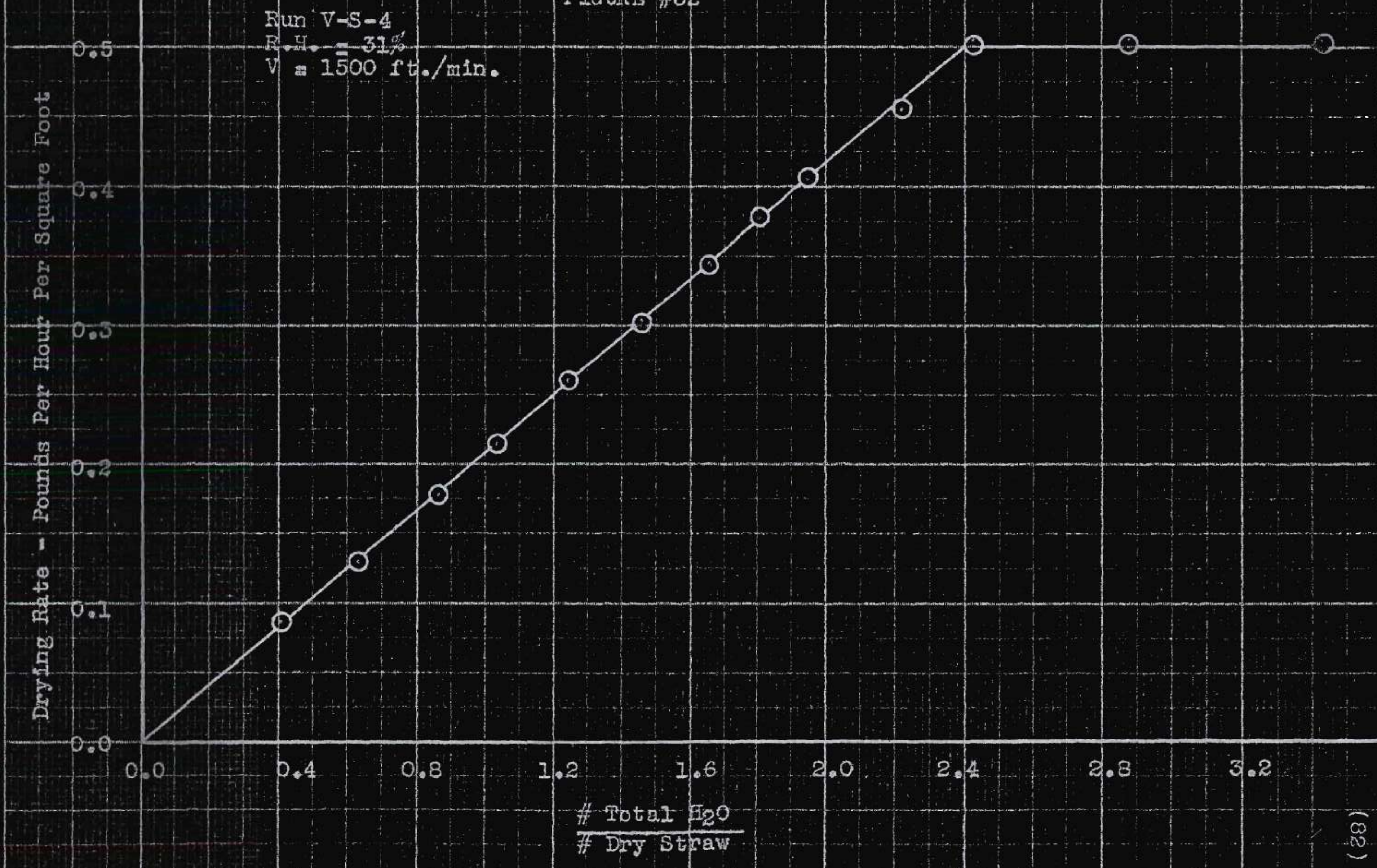
FIGURE #30




DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER RETTED FLAX STRAW
FIGURE #31
Run V-S-2
R.H. = 31%
V = 550 ft./min.
Drying Rate - Pounds Per Hour Per Square Foot
0.00
0.08
0.16
0.24
0.32
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
Total H_2O
Dry Straw
(81)

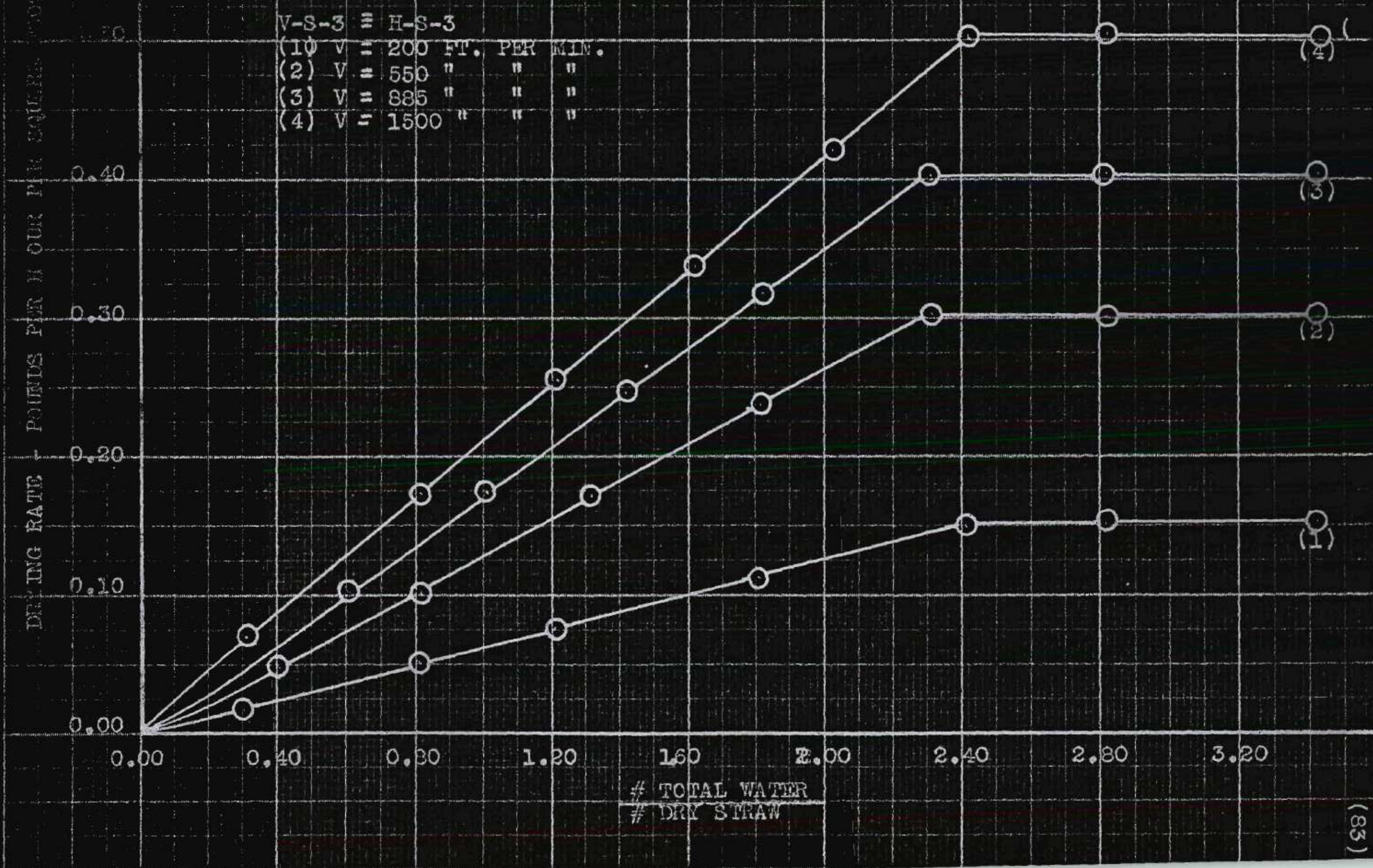
DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION OF WATER RETTED FLAX STRAW

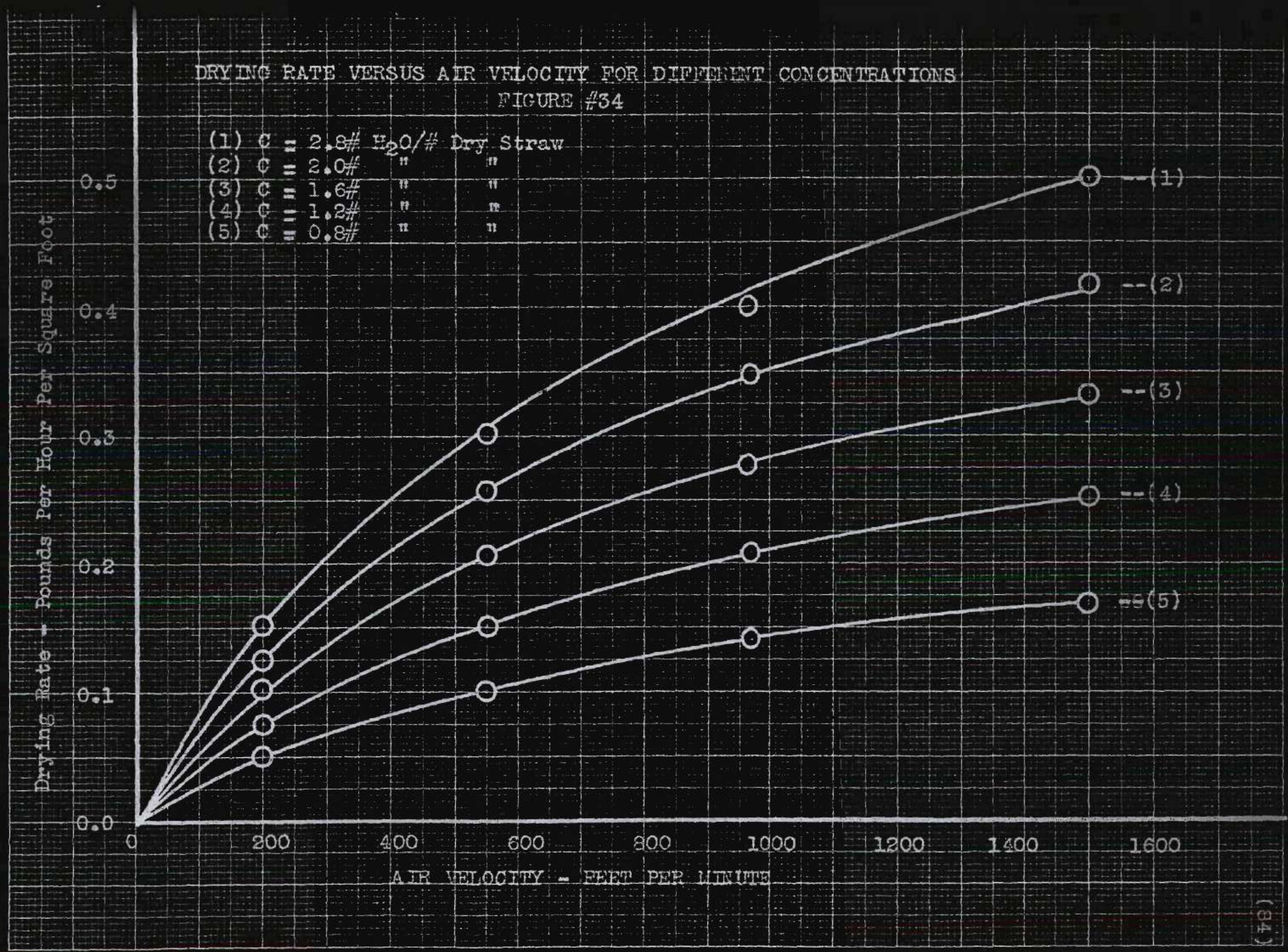
FIGURE #32



EFFECT OF AIR VELOCITY ON THE DRYING RATE OF WATER-RETTED FLAX STRAW

FIGURE # 33





DRYING RATE VERSUS AIR VELOCITY FOR DIFFERENT CONCENTRATIONS
FIGURE #34
(1) C = 2.8# H_2O/# Dry Straw
(2) C = 2.0# " "
(3) C = 1.6# " "
(4) C = 1.2# " "
(5) C = 0.8# " "
--(1)
--(2)
--(3)
--(4)
--(5)
Drying Rate - Pounds Per Hour Per Square Foot
0.0
0.1
0.2
0.3
0.4
0.5
0
200
400
600
800
1000
1200
1400
1600
AIR VELOCITY - FEET PER MINUTE

EFFECT OF VELOCITY OF STRAW

D.B. = 134°F   W.B. = 100°F   Wt. of Assembly = 5.00
R.H. = 31%   Bulk Density = $\frac{0.70\#}{cu.ft.}$ Wt. Dry Straw = 1.70#

RUN V-S-1   V = 200 ft./min.

W lbs.	ΔW lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	Total H_2O / # Dry Straw
12.48	3.50	93.30	0.15	5.78	3.40
11.46	3.50	93.30	0.15	4.76	2.80
10.78	3.50	93.30	0.15	4.08	2.40
10.27	3.20	102.50	0.13	3.57	2.10
9.85	3.20	111.00	0.12	3.15	1.85
9.42	3.10	124.00	0.10	2.72	1.60
9.10	2.60	121.00	0.09	2.40	1.41
8.74	2.60	139.00	0.08	2.04	1.20
8.06	1.80	138.00	0.05	1.36	0.80
7.38	0.80	139.00	0.02	0.68	0.40

RUN V-S-2   V = 550 ft./min.   Wt. assembly = 5.00#
Wt. dry straw = 1.65#

W lbs.	ΔW lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	Total H_2O / # Dry Straw
12.05	4.00	53.40	0.30	5.40	3.30
11.27	4.00	53.40	0.30	4.62	2.80
10.61	3.00	40.00	0.30	3.96	2.40
10.45	3.00	40.00	0.30	3.80	2.30
10.12	2.32	33.80	0.28	3.47	2.10
9.87	2.28	36.50	0.25	3.22	1.95
9.54	2.20	38.30	0.23	2.99	1.81
9.35	1.40	27.30	0.21	2.70	1.64

RUN V-S-2 (cont.)

W lbs.	ΔW lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	Total H_2O #Dry Straw
8.69	1.40	37.40	0.15	2.04	1.24
8.43	0.80	23.20	0.14	1.78	1.08
8.03	0.60	24.00	0.10	1.38	0.84
7.31	0.40	64.00	0.03	0.66	0.40

RUN - V-S-3
V = 885 ft./min.
RUN V-S-3 = H-S-3

RUN V-S-4
V = 1500 ft./min.

Wt. Assembly = 5.00#
Dry Straw = 1.50#

11.44	3.50	28.00	0.50	4.94	3.30
10.77	3.00	24.00	0.50	4.27	2.85
10.10	3.00	24.00	0.50	3.60	2.40
9.80	2.60	23.10	0.45	3.30	2.20
9.42	2.40	24.00	0.40	2.92	1.95
9.20	2.00	21.40	0.38	2.70	1.80
8.97	1.60	18.80	0.34	2.47	1.65
8.66	1.60	21.40	0.30	2.16	1.44
8.34	1.00	15.70	0.26	1.84	1.23
8.01	0.80	15.70	0.21	1.51	1.01
7.78	0.60	13.70	0.18	1.28	0.85
7.41	0.60	19.20	0.13	0.91	0.61
7.10	0.40	19.50	0.08	0.60	0.40

Removal of Heads and Roots.

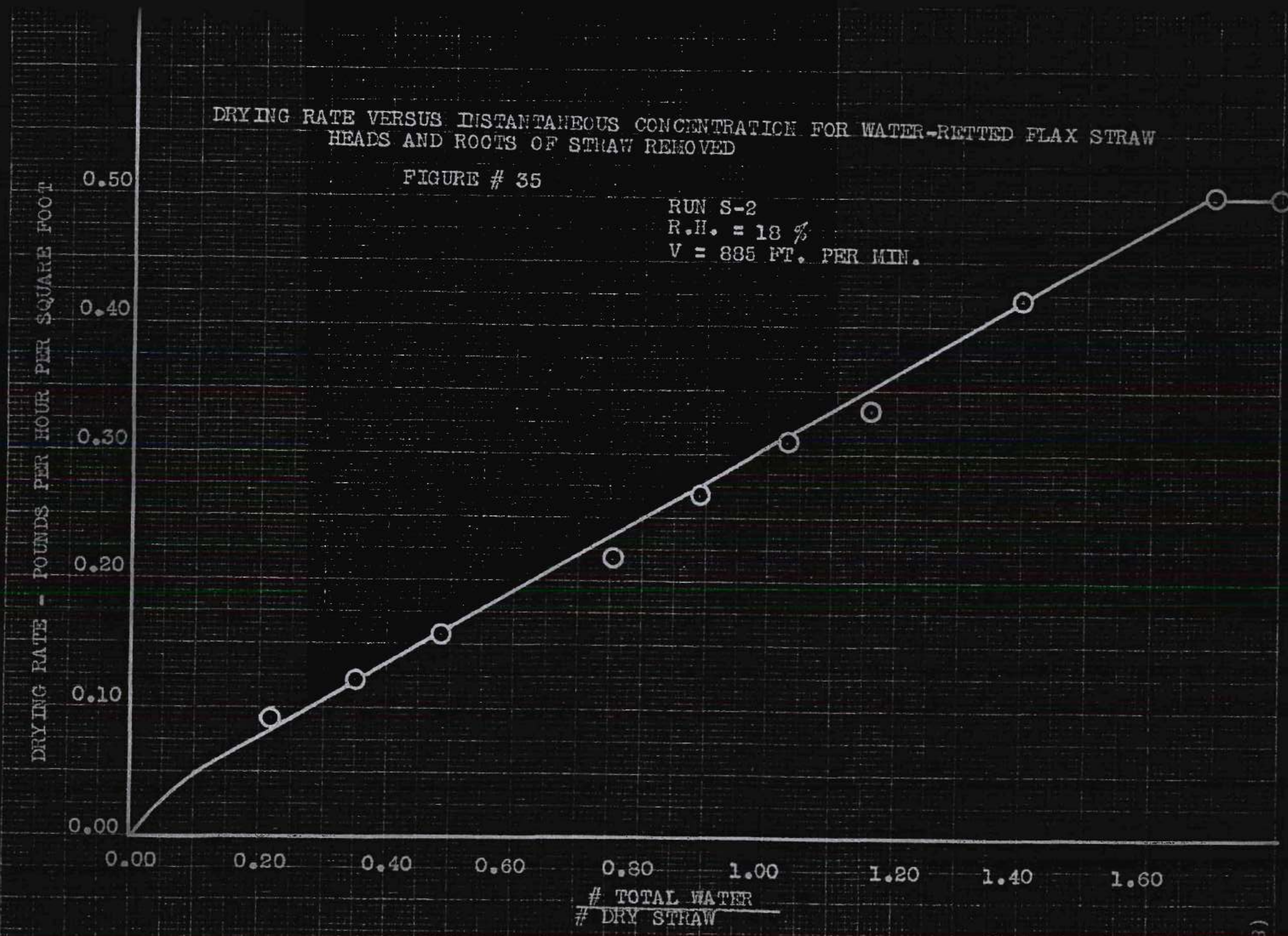
Discussion of Results:

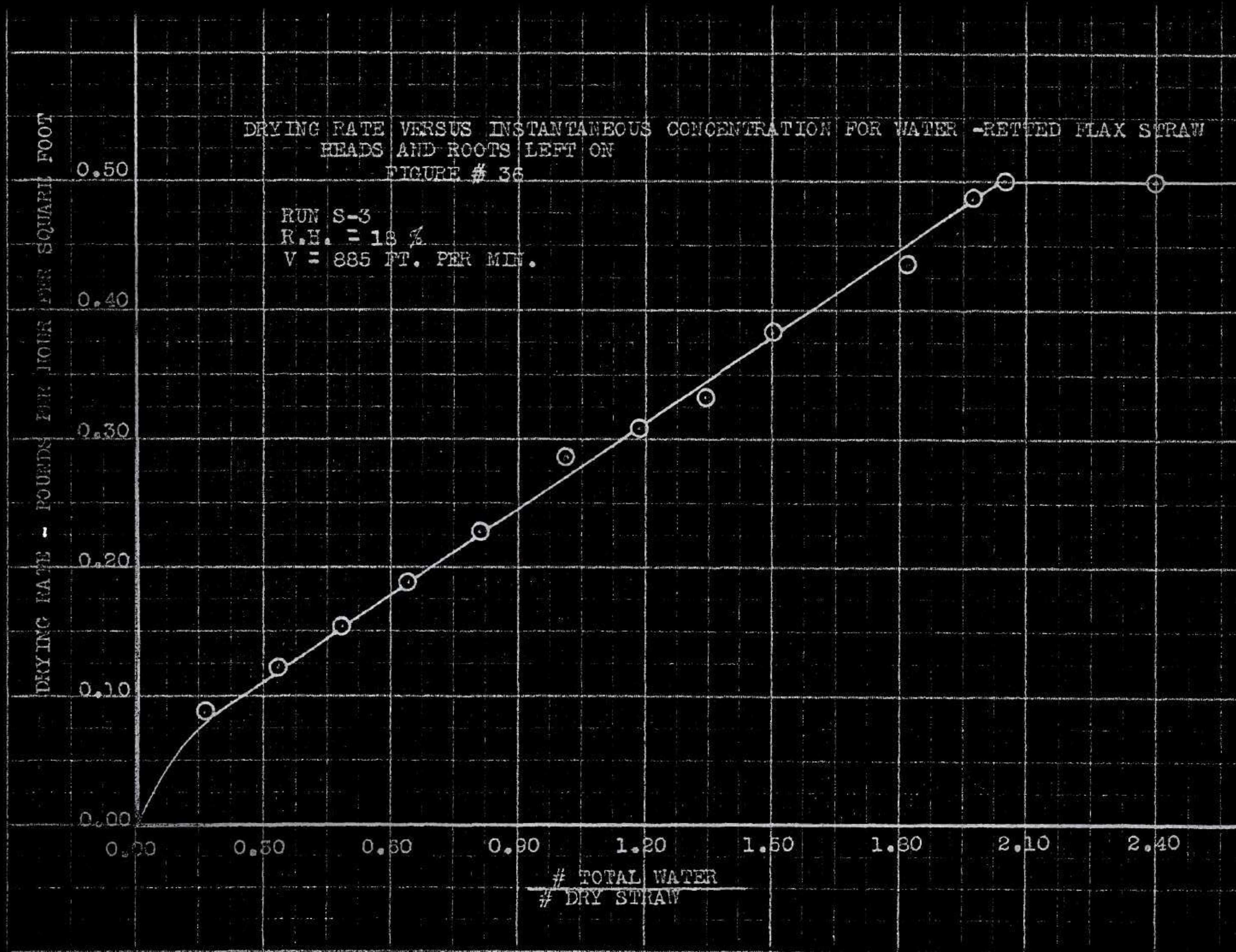
Runs S-2 and S-3, Fig. 35, 36, 37, show the effect of the removal of the heads and roots on the drying rate of flax straw. Both runs were made at a dry-bulb temperature of 150°F, wet-bulb of 100°F and with an air velocity of 885 feet per minute. By removing the heads and roots the individual straws became tapered capillary tubes and allowed a removal of moisture by capillarity from the small ends as well as through the walls of the straw by diffusion.

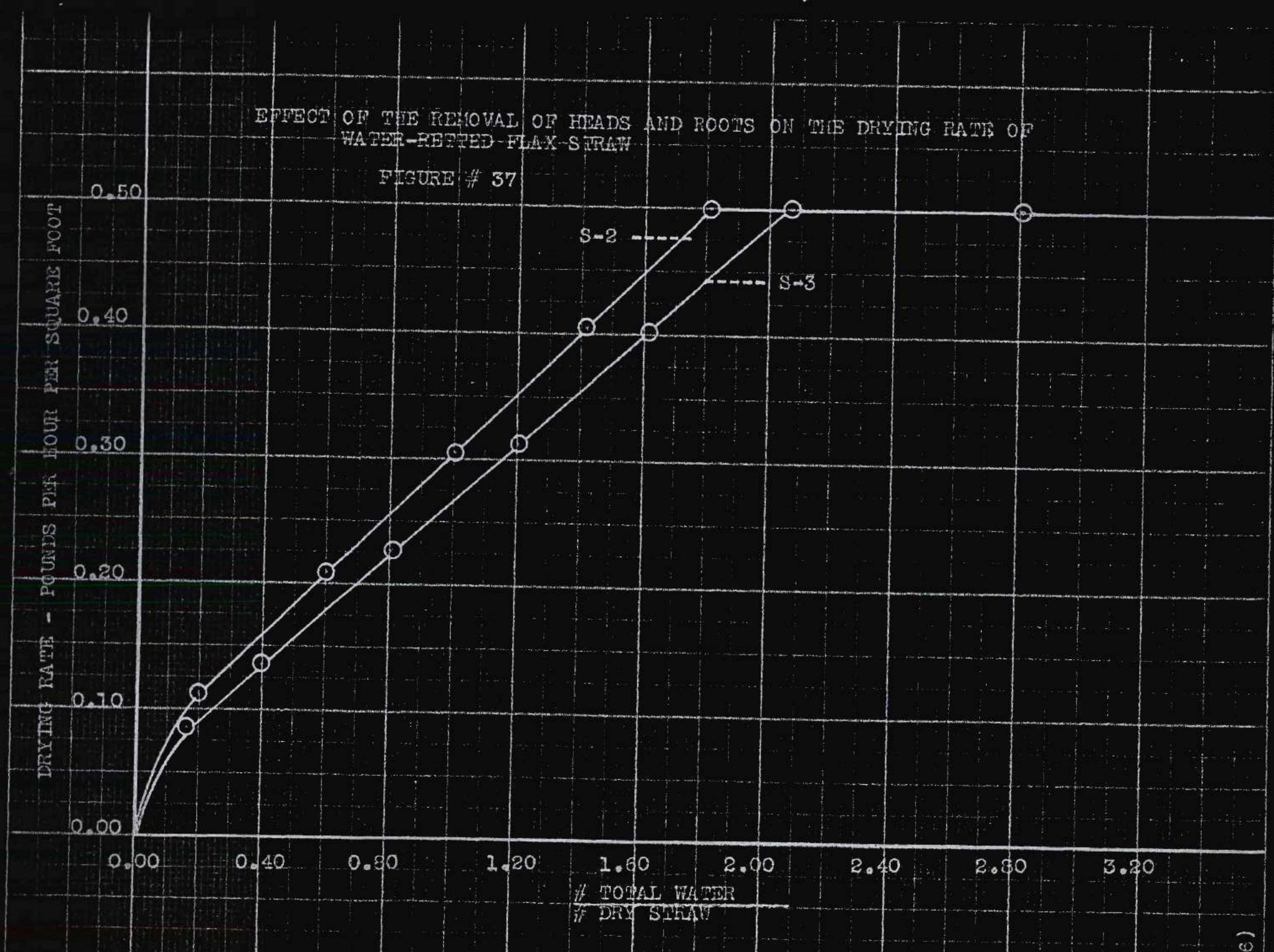
The drying rates were the same during the constant-rate period but a marked difference appears in the falling-rate interval. Removing the ends of the straw reduced the critical moisture content as this operation allowed a longer constant-rate interval due to removal by capillarity as well as by diffusion.

DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER-RETTED FLAX STRAW
HEADS AND ROOTS OF STRAW REMOVED

FIGURE # 35




DRYING RATE VERSUS INSTANTANEOUS CONCENTRATION FOR WATER -RETTED FLAX STRAW
HEADS AND ROOTS LEFT ON
FIGURE # 36
RUN S-3
R.H. = 18 %
V = 885 FT. PER MIN.
DRYING RATE - POUNDS PER HOUR PER SQUARE FOOT
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.30
0.60
0.90
1.20
1.50
1.80
2.10
2.40
TOTAL WATER
DRY STRAW



EFFECT OF THE REMOVAL OF HEADS AND ROOTS ON THE DRYING RATE OF WATER-RETTED-FLAX-STRAW

FIGURE # 37

EFFECT OF REMOVAL OF HEADS AND ROOTS OF STRAW

RUN S-2

D.B. = 150°F
W.B. = 100°F

R.H. = 18%
V = 885 ft./min.

Wt. of Assembly = 6.00#
Wt. Dry Straw = 1.85#

Note: All air conditions are constant.

Heads and Roots Removed.

W lbs.	ΔW lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	# Total H_2O / # Dry Straw
12.00	1.73	14.00	0.50	4.15	2.24
11.10	1.73	14.00	0.50	3.25	1.76
10.63	3.52	37.30	0.38	2.78	1.50
10.00	3.35	42.00	0.32	2.15	1.16
9.75	3.25	43.20	0.30	1.90	1.03
9.50	3.05	46.00	0.27	1.65	0.89
9.25	2.65	48.50	0.22	1.40	0.76
9.00	2.40	52.00	0.19	1.15	0.62
8.75	2.10	55.00	0.15	0.90	0.49
8.50	1.75	56.50	0.12	0.65	0.35
8.25	1.40	58.00	0.10	0.40	0.22

RUN S-3

Wt. Assembly = 6.00# | Heads and Roots on Straw | Dry Straw = 1.50#

W lbs.	ΔW lbs.	ΔT min.	Rate lbs./hr./sq.ft.	Total H_2O lbs.	# Total H_2O / # Dry Straw
11.00	3.00	24.30	0.50	3.50	2.33
10.75	3.00	24.30	0.50	3.25	2.17
10.55	3.00	24.30	0.50	3.08	2.05
10.25	2.95	27.50	0.43	2.75	1.83
10.00	2.85	29.20	0.39	2.50	1.67
9.75	2.80	30.70	0.37	2.25	1.50
9.50	2.68	32.00	0.34	2.00	1.33
9.25	2.58	33.50	0.31	1.75	1.17
9.00	2.49	39.90	0.25	1.50	1.00
8.75	2.14	38.00	0.23	1.25	0.83
8.50	1.88	40.20	0.19	1.00	0.67
8.25	1.60	42.00	0.15	0.75	0.50
8.00	1.30	42.80	0.12	0.50	0.33
7.75	0.90	42.00	0.09	0.25	0.17

IX GENERAL DISCUSSION OF ALL RESULTS

In all runs the area used in the calculation of drying rates was taken as twice that of the containing basket. The actual total area of the individual fibers or straws exposed to the drying air is, of course, indeterminate but since all design calculations would have to be based upon the former area, its use in these calculations is well justified. Several runs were made utilizing an extra fan located within the dryer which forced air perpendicularly against the bottom of the material while the main blower delivered air parallel to the stock. This procedure increased the drying rates considerably but the effective air velocity could not be determined so these determinations are not included in the thesis. Perpendicular flow of air seems to be more effective for the removal of moisture from these two materials than parallel flow of air.

The effect of velocity on the drying rates of flax fibers and straw is intensive during the constant-rate period, the intensity diminishing as the materials approach dryness. High air velocities are very important in securing fast drying rates.

Air humidity has an important effect on the drying rates of these materials but drying rates may be boosted at high humidities by the use of a higher air velocity. The humidity of the air leaving any drying apparatus should not exceed 60 percent, because the drying rates are greatly impaired by excessive humidities and the saving effected in circulating smaller volumes of air is minimized by the reduction in the drying rates.

A large percentage of water may be removed from the fibers by mechanical means without any injury to the material and this operation should always be carried out before exposing the stock to the drying air. This procedure will effect a large saving in drying costs. The mechanical removal of water from flax straw presents a more difficult problem as the straw would be crushed under pressure and the use of this operation would depend on the required condition of the straw for subsequent treatments. It would seem that any method (squeeze rolls) that would crush the woody section of the straw and not harm the fibers would increase the drying rate by decreasing the diffusional resistance and would also decrease the cost of drying.

BIBLIOGRAPHY

Sherwood, T.K., American Institute of Chemical Engineers, 32, 150, (1936)

______, Industrial Engineering Chemistry, 22, 132, (1930)

______, Industrial Engineering Chemistry, 21, 12, (1929)

______, Industrial Engineering Chemistry, 24, 307, (1932)

Newman, American Institute of Chemical Engineers, 27, 203, (1931)

______, American Institute of Chemical Engineers, 27, 310, (1931)

Lederer, Zeit. Angew. Chem., 37, 750, (1924)

Molstad, Farevaag and Farrell, Industrial Engineering Chemistry, 32, 150, (1936)

McCready and McCabe, American Institute of Chemical Engineers, 29, 131, (1933)

Lewis, Industrial Engineering Chemistry, 13, 427, (1921)

Sherwood and Comings, Industrial Engineering Chemistry, 26, 1096, (1934)

Walker, Lewis, McAdams and Gilliland, Principles of Chemical Engineering.